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# Chapter Nine
# HORIZONTAL ALIGNMENT

The horizontal alignment of a highway facility will have a significant impact on vehicular operation and construction costs. Chapter Nine presents the Department's criteria for horizontal alignment elements, including minimum radii, usage of horizontal curve types, superelevation rates and development, sight distance around horizontal curves and mathematical details for computing horizontal curves.

## 9.1 GENERAL CONTROLS

The design of horizontal alignment involves, to a large extent, complying with specific limiting criteria. These include minimum radii, superelevation rates and sight distance. In addition, the designer should adhere to general design principles and controls which will determine the overall safety of the facility and will enhance the aesthetic appearance of the highway. These general controls include:

1. Consistency. Alignment should be consistent. Avoid sharp curves at the ends of long tangents and sudden changes from gentle to sharply curving alignment.

2. Directional. Alignment should be as directional as practical and consistent with physical and economic constraints. On divided highways a flowing line that conforms generally to the natural contours is preferable to one with long tangents that slash through the terrain. Directional alignment can be achieved by using the smallest practical central angles.

3. Use of Minimum Radii. The use of minimum radii should be avoided if practical.

4. High Fills. Avoid sharp curves on long, high fills. Under these conditions, it is difficult for drivers to perceive the extent of horizontal curvature.

5. Alignment Reversals. Avoid abrupt reversals in alignment ("S" or reverse curves). Provide a sufficient tangent distance between the curves to ensure proper superelevation transitions for both curves.

6. Broken-Back Curvature. Avoid where practical. This arrangement is not aesthetically pleasing, violates driver expectancy and creates undesirable superelevation development requirements.

7. Compound Curves. Avoid the use of compound curves on highway mainline. These may "fool" the driver when judging the sharpness of a horizontal curve.

8. Coordination with Natural/Man-Made Features. The horizontal alignment should be properly coordinated with the natural topography, available right-of-way, utilities, roadside development and natural/man-made drainage patterns.

9. Environmental Impacts. Horizontal alignment should be properly coordinated with environmental impacts (e.g., encroachment onto wetlands).

10. Intersections. Horizontal alignment through intersections may present special problems (e.g., intersection sight distance, superelevation development). See Chapter Twenty-eight in the *Montana Traffic Engineering Manual* for the design of intersections at-grade.

11. Coordination with Vertical Alignment. Chapter Ten discusses general design principles for the coordination between horizontal and vertical alignment.

12. Visibility. Design the roadway so that the driver has a clear view of the alignment

## 9.2 HORIZONTAL CURVES

### 9.2.1 Definitions

1. Simple Curves. These are continuous arcs of constant radius which achieve the necessary highway deflection without an entering or exiting transition.

2. Compound Curves. These are a series of two or more horizontal curves with deflections in the same direction immediately adjacent to each other.

3. Spiral Curves. These are curvature arrangements used to transition between a tangent section and a simple curve which are consistent with the transitional characteristics of vehicular turning paths. When moving from the tangent to the simple curve, the sharpness of the spiral curve gradually increases from a radius of infinity to the radius of the simple curve.

4. Reverse Curves. These are two simple curves with deflections in opposite directions which are joined by a common point or a relatively short tangent distance.

5. Broken-Back Curves. Broken-back curves are two closely spaced horizontal curves with deflections in the same direction and a short intervening tangent.

### 9.2.2 Selection of Curve Type

The following presents MDT practice for the selection of the type of horizontal curve based on the type of facility:

1. Rural State Highways and High-Speed ($V > 70$ km/h) Urban Roadways. Based on the curve radii, the following will apply:

    a. $R \leq 1165$ m — use a spiral curve.

    b. $R > 1165$ m — use a simple curve.

Compound curves are not allowed on these facilities, except in transitional areas.

2. Low-Speed ($V \leq 70$ km/h) Urban Roadways/Non-State Highways. Typically, simple curves will be used on low-speed urban roadways and non-State highways. In urban areas, if necessary, it is acceptable to use compound curves on the mainline to:

a. avoid obstructions,
b. avoid right-of-way problems, and/or
c. fit the existing topography.

Where used, compound curves on mainline should be designed such that the radius of the flatter curve is no more than 1.5 times the radius of the sharper curve (i.e., $R_1 \leq 1.5 R_2$, where $R_1$ is the flatter curve).

## 9.2.3 Calculation of Curve Radius

### 9.2.3.1 Basic Curve Equation

The point-mass formula is used to define vehicular operation around a curve. Where the curve is expressed using its radius, the basic equation for a simple curve is:

$$R = \frac{V^2}{127(e + f)} \qquad \text{(Equation 9.2-1)}$$

where:

$R$ = radius of curve, m
$e$ = superelevation rate, decimal
$f$ = side-friction factor, decimal
$V$ = vehicular speed, km/h

### 9.2.3.2 General Theory

Establishing horizontal curvature criteria requires a selection of the theoretical basis for the various factors in the basic curve equation. These include the selection of maximum side-friction factors (f) and the distribution method between side friction and superelevation. For highway mainlines, the theoretical basis will be one of the following:

1. Open-Roadway Conditions. The theoretical basis for horizontal curvature assuming open-roadway conditions includes:

   a. relatively low maximum side-friction factors (i.e., a relatively small level of driver discomfort); and

   b. the use of AASHTO Method 5 to distribute side friction and superelevation.

AASHTO Method 5 distributes side friction and superelevation such that each element is used simultaneously to offset the outward pull of the vehicle traveling around the curve.

Open-roadway conditions apply to all rural facilities and to all high-speed urban facilities; i.e., where the design speed (V) >70 km/h.

2. Low-Speed Urban Streets. The theoretical basis for horizontal curvature assuming low-speed urban street conditions includes:

   a. relatively high maximum side-friction factors to reflect a higher level of driver acceptance of discomfort; and

   b. the use of AASHTO Method 2 to distribute side friction and superelevation.

   AASHTO Method 2 distributes side friction and superelevation such that side friction alone is used, up to $f_{max}$, to offset the outward pull of the vehicle traveling around the curve. Only then is superelevation introduced.

   Low-speed urban streets are defined as streets within an urban or urbanized area where the design speed (V) $\leq$ 70 km/h. Designers should check local design criteria for off-system facilities.

### 9.2.4 Minimum Radii

Figures 9.2A and 9.2B present the minimum radii ($R_{min}$) for open-roadway facilities and low-speed urban streets. To define $R_{min}$, a maximum superelevation rate ($e_{max}$) must be selected. See Section 9.3 for MDT criteria for $e_{max}$.

### 9.2.5 Selection of Curve Radius

Where practical, the designer will select curve radii from among the radii listed in Figure 9.2C for mainline on open roadways. This will provide uniformity in project design. At individual curves, however, it may be necessary to select radii intermittent between those in the figure, rounded to the next highest 5 m increment. Curve radii on low-speed urban streets will be selected on a case-by-case basis.

| Design Speed, V (km/h) | $e_{max}$ | $f_{max}$ | Minimum Radii, $R_{min}$ (m) |
|---|---|---|---|
| 30 | 8.0% | 0.17 | 30 |
| 40 | 8.0% | 0.17 | 50 |
| 50 | 8.0% | 0.16 | 80 |
| 60 | 8.0% | 0.15 | 125 |
| 70 | 8.0% | 0.14 | 175 |
| 80 | 8.0% | 0.14 | 230 |
| 90 | 8.0% | 0.13 | 305 |
| 100 | 8.0% | 0.12 | 395 |
| 110 | 8.0% | 0.11 | 500 |

*Note: $R_{min}$ is based on Equation 9.2-1 rounded to the nearest 5 m increment.*

**MINIMUM RADII**
**(Open-Roadway Conditions)**

**Figure 9.2A**

| Design Speed, V (km/h) | $e_{max}$ | $f_{max}$ | Minimum Radii, $R_{min}$ (m) |
|---|---|---|---|
| 30 | 4.0% | 0.312 | 20 |
| 40 | 4.0% | 0.252 | 45 |
| 50 | 4.0% | 0.214 | 80 |
| 60 | 4.0% | 0.186 | 125 |
| 70 | 4.0% | 0.163 | 190 |

*Note: Rmin is based on Equation 9.2-1 rounded to the nearest 5 m increment.*

**MINIMUM RADII**

**(Low-Speed Urban Streets ($V \leq 70$ km/h))**

**Figure 9.2B**

| Select curve radii from the following | |
|---|---|
| 7000 m | 450 m |
| 3500 m | 350 m |
| 2350 m | 300 m |
| 1750 m | 250 m |
| 1150 m | 220 m |
| 900 m | 190 m |
| 700 m | 170 m |
| 600 m | 160 m |
| 500 m | 150 m |

**SELECTION OF CURVE RADII**
**(Open Roadways)**

**Figure 9.2C**

### 9.2.6 Maximum Deflection Without Curve

It may be appropriate to design a facility without a horizontal curve where small deflection angles (Δ) are present. As a guide, the designer may retain deflection angles of about 1° or less (urban) and 0.5° or less (rural) for the highway mainline. In these cases, the absence of a horizontal curve will not likely affect driver response or aesthetics.

For highway mainline at urban intersections, higher deflection angles may be acceptable based on an evaluation of the design speed, traffic volumes, functional class, existing/future signalization, etc.

### 9.2.7 Minimum Length of Curve

Short horizontal curves may provide the driver with the appearance of a kink in the alignment. To improve the aesthetics of the highway, the designer should lengthen short curves, if practical, even if not necessary for engineering reasons. The following guidance should be used to establish minimum curve lengths for deflection angles (Δ) of 5° or less:

1. Open Roadways. For open roadways, use the following criteria that results in the greatest curve length:

    a. The minimum radius that results in a normal crown cross slope.
    b. The length of curve in meters = 3V, where V is the design speed in km/h.
    c. A 150 m length of curve.

    If this criteria cannot be met, the designer should document this in the Alignment Review Report.

2. Urban. The minimum length of curves on low-speed urban streets will be determined on a case-by-case basis.

### 9.2.8 Computation

Section 9.6 presents the applicable mathematical details for the computation of horizontal curves.

## 9.3 SUPERELEVATION (OPEN-ROADWAY CONDITIONS)

### 9.3.1 Definitions

1. Superelevation. Superelevation is the amount of cross slope or "bank" provided on a horizontal curve to help counterbalance the outward pull of a vehicle traversing the curve.

2. Maximum Superelevation ($e_{max}$). The maximum rate of superelevation ($e_{max}$) is an overall superelevation control used on a specific facility. Its selection depends on several factors including overall climatic conditions, terrain conditions, type of facility and type of area (rural or urban).

3. Superelevation Transition Length. The superelevation transition length is the distance required to transition the roadway from a normal crown section to full superelevation. Superelevation transition length is the sum of the tangent runout (TR) and superelevation runoff (L) distances:

    a. Tangent Runout (TR). Tangent runout is the distance needed to transition the roadway from a normal crown section to a point where the adverse cross slope of the outside lane or lanes is removed (i.e., the outside lane(s) is level).

    b. Superelevation Runoff (L). Superelevation runoff is the distance needed to transition the cross slope from the end of the tangent runout (adverse cross slope removed) to a section that is sloped at the design superelevation rate.

4. Axis of Rotation. The superelevation axis of rotation is the line about which the pavement is revolved to superelevate the roadway. This line will maintain the normal highway profile throughout the curve.

5. Superelevation Rollover. Superelevation rollover is the algebraic difference (A) between the superelevated traveled way slope and shoulder slope on the outside of a horizontal curve.

6. Relative Longitudinal Slope. The relative longitudinal slope is the difference between the centerline grade and the grade of the edge of traveled way.

7. Open Roadways. Open roadways are all rural facilities regardless of design speed and all urban facilities with a design speed greater than 70 km/h.

8. Low-Speed Urban Streets. These are all streets within urbanized and small urban areas with a design speed of 70 km/h or less.

### 9.3.2 Maximum Superelevation Rate

The selection of a maximum rate of superelevation ($e_{max}$) depends upon several factors. These include urban/rural location, type of facility and prevalent climatic conditions within Montana. For open-roadway conditions, MDT has adopted the following for the selection of $e_{max}$:

1. Rural Facilities. An $e_{max}$ = 8.0% is used on all rural facilities for all design speeds.

2. Urban Facilities (V > 70 km/h). An $e_{max}$ = 8.0% is used on all urban facilities where the design speed (V) is greater than 70 km/h.

### 9.3.3 Superelevation Rates

Based on the selection of $e_{max}$ and the use of AASHTO Method 5 to distribute e and f, the following figures allow the designer to select the superelevation rate for combinations of curve radii (R) and design speed (V) and to select the minimum length of transition:

1. Figure 9.3A applies to 2-lane, 2-way highways where $e_{max}$ = 8.0%.

2. Figure 9.3B applies to 4-lane divided and undivided facilities where $e_{max}$ = 8.0%.

Note that superelevation rates are a controlling criteria. The designer must seek a design exception for any proposed rate which does not meet the criteria in Figures 9.3A and 9.3B. See Section 8.8 for Department procedures on design exceptions.

| e | V = 50 km/h | | | V = 60 km/h | | | V = 70 km/h | | |
|---|---|---|---|---|---|---|---|---|---|
| | R(m) | Trans. Length | | R(m) | Trans. Length | | R(m) | Trans. Length | |
| | | L(m) | TR(m) | | L(m) | TR(m) | | L(m) | TR(m) |
| NC | R ≥ 1090 | 0 | 0 | R ≥ 1495 | 0 | 0 | R ≥ 1970 | 0 | 0 |
| 2.0% | 1090 > R ≥ 795 | 30 | 30.00 | 1495 > R ≥ 1095 | 35 | 35.00 | 1970 > R ≥ 1445 | 40 | 40.00 |
| 3.0% | 795 > R ≥ 500 | 30 | 20.00 | 1095 > R ≥ 700 | 35 | 23.33 | 1445 > R ≥ 925 | 40 | 26.67 |
| 4.0% | 500 > R ≥ 350 | 30 | 15.00 | 700 > R ≥ 490 | 35 | 17.50 | 925 > R ≥ 650 | 40 | 20.00 |
| 5.0% | 350 > R ≥ 260 | 30 | 12.00 | 490 > R ≥ 365 | 35 | 14.00 | 650 > R ≥ 490 | 40 | 16.00 |
| 6.0% | 260 > R ≥ 190 | 35 | 11.67 | 365 > R ≥ 270 | 40 | 13.33 | 490 > R ≥ 370 | 40 | 13.33 |
| 7.0% | 190 > R ≥ 135 | 40 | 11.43 | 270 > R ≥ 200 | 45 | 12.86 | 370 > R ≥ 275 | 50 | 14.29 |
| 8.0% | 135 > R ≥ 80 | 45 | 11.25 | 200 > R ≥ 125 | 50 | 12.50 | 275 > R ≥ 175 | 55 | 13.75 |
| | $R_{min}$ = 80 m | | | $R_{min}$ = 125 m | | | $R_{min}$ = 175 m | | |

| e | V = 80 km/h | | | V = 90 km/h | | | V = 100 km/h | | |
|---|---|---|---|---|---|---|---|---|---|
| | R(m) | Trans. Length | | R(m) | Trans. Length | | R(m) | Trans. Length | |
| | | L(m) | TR(m) | | L(m) | TR(m) | | L(m) | TR(m) |
| NC | R ≥ 2440 | 0 | 0 | R ≥ 2965 | 0 | 0 | R ≥ 3625 | 0 | 0 |
| 2.0% | 2440 > R ≥ 1795 | 45 | 45.00 | 2965 > R ≥ 2185 | 50 | 55.00 | 3625 > R ≥ 2675 | 60 | 60.00 |
| 3.0% | 1795 > R ≥ 1170 | 45 | 30.00 | 2185 > R ≥ 1400 | 50 | 33.33 | 2675 > R ≥ 1750 | 60 | 40.00 |
| 4.0% | 1170 > R ≥ 825 | 45 | 22.50 | 1400 > R ≥ 1000 | 50 | 25.00 | 1750 > R ≥ 1250 | 60 | 30.00 |
| 5.0% | 825 > R ≥ 620 | 45 | 18.00 | 1000 > R ≥ 770 | 50 | 20.00 | 1250 > R ≥ 950 | 60 | 24.00 |
| 6.0% | 620 > R ≥ 475 | 45 | 15.00 | 770 > R ≥ 600 | 50 | 16.67 | 950 > R ≥ 750 | 60 | 20.00 |
| 7.0% | 475 > R ≥ 360 | 55 | 15.71 | 600 > R ≥ 465 | 55 | 15.71 | 750 > R ≥ 590 | 60 | 17.14 |
| 8.0% | 360 > R ≥ 230 | 60 | 15.00 | 465 > R ≥ 305 | 65 | 16.25 | 590 > R ≥395 | 65 | 16.25 |
| | $R_{min}$ = 230 m | | | $R_{min}$ = 305 m | | | $R_{min}$ = 395 m | | |

| e | V = 110 km/h | | |
|---|---|---|---|
| | R(m) | Trans. Length | |
| | | L(m) | TR(m) |
| NC | R ≥ 4180 | 0 | 0 |
| 2.0% | 4180 > R ≥ 3095 | 65 | 65.00 |
| 3.0% | 3095 > R ≥ 2000 | 65 | 43.33 |
| 4.0% | 2000 > R ≥ 1465 | 65 | 32.50 |
| 5.0% | 1465 > R ≥ 1140 | 65 | 26.00 |
| 6.0% | 1140 > R ≥ 900 | 65 | 21.67 |
| 7.0% | 900 > R ≥ 735 | 65 | 18.57 |
| 8.0% | 735 > R ≥ 500 | 70 | 17.50 |
| | $R_{min}$ = 500 m | | |

$e_{max}$ = 8.0%

Key:

R = Radius of curve, m
V = Design speed, km/h
e = Superelevation rate, %
L = Minimum length of superelevation runoff (from adverse slope removed to full super), m
TR = Tangent runout from NC to adverse slope removed, m
NC = Normal crown = 2.0%

Note: See Figure 9.2C for typical selection of curve radii.

**RATE OF SUPERELEVATION AND MINIMUM LENGTH OF TRANSITION**
**(Two-Lane, Two-Way Highways; Open Roadways)**

**Figure 9.3A**

| e | V = 50 km/h | | | V = 60 km/h | | | V = 70 km/h | | |
|---|---|---|---|---|---|---|---|---|---|
| | R(m) | Trans. Length | | R(m) | Trans. Length | | R(m) | Trans. Length | |
| | | L(m) | TR(m) | | L(m) | TR(m) | | L(m) | TR(m) |
| NC | R ≥ 1090 | 0 | 0 | R ≥ 1495 | 0 | 0 | R ≥ 1970 | 0 | 0 |
| 2.0% | 1090 > R ≥ 795 | 30 | 30.00 | 1495 > R ≥ 1095 | 35 | 35.00 | 1970 > R ≥ 1445 | 40 | 40.00 |
| 3.0% | 795 > R ≥ 500 | 30 | 20.00 | 1095 > R ≥ 700 | 35 | 23.33 | 1445 > R ≥ 925 | 40 | 26.67 |
| 4.0% | 500 > R ≥ 350 | 35 | 17.50 | 700 > R ≥ 490 | 40 | 20.00 | 925 > R ≥ 650 | 40 | 20.00 |
| 5.0% | 350 > R ≥ 260 | 45 | 18.00 | 490 > R ≥ 365 | 50 | 20.00 | 650 > R ≥ 490 | 50 | 20.00 |
| 6.0% | 260 > R ≥ 190 | 50 | 16.67 | 365 > R ≥ 270 | 50 | 18.33 | 490 > R ≥ 370 | 60 | 20.00 |
| 7.0% | 190 > R ≥ 135 | 60 | 17.14 | 270 > R ≥ 200 | 65 | 18.57 | 370 > R ≥ 275 | 70 | 20.00 |
| 8.0% | 135 > R ≥ 80 | 65 | 16.25 | 200 > R ≥ 125 | 75 | 18.75 | 275 > R ≥ 175 | 80 | 20.00 |
| | $R_{min}$ = 80 m | | | $R_{min}$ = 125 m | | | $R_{min}$ = 175 m | | |

| e | V = 80 km/h | | | V = 90 km/h | | | V = 100 km/h | | |
|---|---|---|---|---|---|---|---|---|---|
| | R(m) | Trans. Length | | R(m) | Trans. Length | | R(m) | Trans. Length | |
| | | L(m) | TR(m) | | L(m) | TR(m) | | L(m) | TR(m) |
| NC | R ≥ 2440 | 0 | 0 | R ≥ 2965 | 0 | 0 | R ≥ 3625 | 0 | 0 |
| 2.0% | 2440 > R ≥ 1795 | 45 | 45.00 | 2965 > R ≥ 2185 | 50 | 50.00 | 3625 > R ≥ 2675 | 60 | 60.00 |
| 3.0% | 1795 > R ≥ 1170 | 45 | 30.00 | 2185 > R ≥ 1400 | 50 | 33.33 | 2675 > R ≥ 1750 | 60 | 40.00 |
| 4.0% | 1170 > R ≥ 825 | 45 | 22.50 | 1400 > R ≥ 1000 | 50 | 25.00 | 1750 > R ≥ 1250 | 60 | 30.00 |
| 5.0% | 825 > R ≥ 620 | 55 | 22.00 | 1000 > R ≥ 770 | 60 | 24.00 | 1250 > R ≥ 950 | 60 | 24.00 |
| 6.0% | 620 > R ≥ 475 | 65 | 21.67 | 770 > R ≥ 600 | 70 | 23.33 | 950 > R ≥ 750 | 75 | 25.00 |
| 7.0% | 475 > R ≥ 360 | 80 | 22.86 | 600 > R ≥ 465 | 80 | 22.86 | 750 > R ≥ 590 | 85 | 24.29 |
| 8.0% | 360 > R ≥ 230 | 90 | 22.50 | 465 > R ≥ 305 | 95 | 23.75 | 590 > R ≥395 | 100 | 25.00 |
| | $R_{min}$ = 230 m | | | $R_{min}$ = 305 m | | | $R_{min}$ = 395 m | | |

| e | V = 110 km/h | | |
|---|---|---|---|
| | R(m) | Trans. Length | |
| | | L(m) | TR(m) |
| NC | R ≥ 4180 | 0 | 0 |
| 2.0% | 4180 > R ≥ 3095 | 65 | 65.00 |
| 3.0% | 3095 > R ≥ 2000 | 65 | 43.33 |
| 4.0% | 2000 > R ≥ 1465 | 65 | 32.50 |
| 5.0% | 1465 > R ≥ 1140 | 65 | 26.00 |
| 6.0% | 1140 > R ≥ 900 | 80 | 26.67 |
| 7.0% | 900 > R ≥ 735 | 90 | 25.71 |
| 8.0% | 735 > R ≥ 500 | 105 | 26.25 |
| | $R_{min}$ = 500 m | | |

$e_{max}$ = 8.0%

Key:

R = Radius of curve, m

V = Design speed, km/h

e = Superelevation rate, %

L = Minimum length of superelevation runoff (from adverse slope removed to full super), m

TR = Tangent runout from NC to adverse slope removed, m

NC = Normal crown = 2.0%

Note: See Figure 9.2C for typical selection of curve radii.

**RATE OF SUPERELEVATION AND MINIMUM LENGTH OF TRANSITION**
**(Multilane Highways; Open Roadways)**

**Figure 9.3B**

## 9.3.4 Minimum Radii Without Superelevation

A horizontal curve with a sufficiently large radius does not require superelevation, and the normal crown (NC) used on tangent sections can be maintained throughout the curve. Figures 9.3A and 9.3B indicate the threshold (or minimum) radius for a normal crown section at various design speeds. This threshold is based on a theoretical superelevation rate of +1.5%.

## 9.3.5 Transition Length

As defined in Section 9.3.1, the superelevation transition length is the distance required to transition the roadway from a normal crown section to the full design superelevation. The superelevation transition length is the sum of the tangent runout distance (TR) and superelevation runoff length (L).

### 9.3.5.1 Two-Lane Roadways

Superelevation Runoff

Figure 9.3A presents the superelevation runoff lengths for 2-lane roadways for various combinations of curve radii, design speed and superelevation rate. The lengths are calculated as follows:

$$L = e \times W \times RS \geq L_{min} \qquad \text{(Equation 9.3-1)}$$

where:

$L$ = Superelevation runoff length for a 2-lane roadway, m

$W$ = Width of travel lane (assumed to be 3.6 m)

$RS$ = Reciprocal of relative longitudinal slope between the roadway centerline and outside edge of traveled way (see Figure 9.3C)

$e$ = Superelevation rate, decimal

$L_{min}$ = Minimum superelevation runoff length regardless of calculated L (see Figure 9.3D), m

| Design Speed (km/h) | RS | Maximum Relative Longitudinal Slope, G(%)* |
|---|---|---|
| 50 | 150 | 0.65 |
| 60 | 167 | 0.60 |
| 70 | 182 | 0.55 |
| 80 | 200 | 0.50 |
| 90 | 210 | 0.48 |
| 100 | 222 | 0.45 |
| 110 | 238 | 0.42 |

* G(%) = 1/RS x 100

**MAXIMUM RELATIVE LONGITUDINAL SLOPES**
**(Two-Lane Roadways)**

**Figure 9.3C**

| Design Speed(km/h) | Minimum Superelevation Runoff Lengths (m) |
|---|---|
| 50 | 30 |
| 60 | 35 |
| 70 | 40 |
| 80 | 45 |
| 90 | 50 |
| 100 | 60 |
| 110 | 65 |

**MINIMUM SUPERELEVATION**
**RUNOFF LENGTHS ($L_{min}$)**

**Figure 9.3D**

The calculated L values are subject to minimum lengths ($L_{min}$), which are based on approximately two seconds of travel time. Note that, where the calculated numbers apply, L has been rounded up to the next highest 5 m increment in Figure 9.3A.

Tangent Runout

Figure 9.3A presents the tangent runout distances based on a 2.0% normal crown for 2-lane roadways. For roadways having a normal crown other than 2%, use Equation 9.3-2 to compute the tangent runout distance. The distance is calculated as follows:

$$TR = \frac{S_{NORMAL}}{e/L} = \frac{(S_{NORMAL})(L)}{e} \qquad \text{(Equation 9.3-2)}$$

where:

| | | |
|---|---|---|
| $TR$ | = | Tangent runout distance for a 2-lane roadway, m |
| $S_{NORMAL}$ | = | Travel lane cross slope on tangent (typically 2.0%), decimal |
| $e$ | = | Design superelevation rate (i.e., full superelevation for horizontal curve), decimal |
| $L$ | = | Superelevation runoff length for a 2-lane roadway, m (Equation 9.3-1) |

The values in Figure 9.3A are presented to the nearest hundredth of a meter. This will ensure that the relative longitudinal gradient of the tangent runout equals that of the superelevation runoff.

### 9.3.5.2 Multilane Highways

Superelevation Runoff

The superelevation runoff distance for multilane highways is calculated by:

$$L = 1.5 \times e \times W \times RS \geq L_{min} \qquad \text{(Equation 9.3-3)}$$

where the terms are as defined for Equation 9.3-1 for 2-lane highways. The calculated runoff lengths for multilane facilities are 1.5 times those for 2-lane facilities. The longer lengths are more appropriate for major facilities considering higher traffic volumes and the desire to provide a higher level of driver comfort.

Figure 9.3B presents the superelevation runoff distances for multilane facilities which are either the $L_{min}$ values (Figure 9.3D) or the calculated values (Equation 9.3-3) rounded up to the next highest 5 m increment.

Tangent Runout

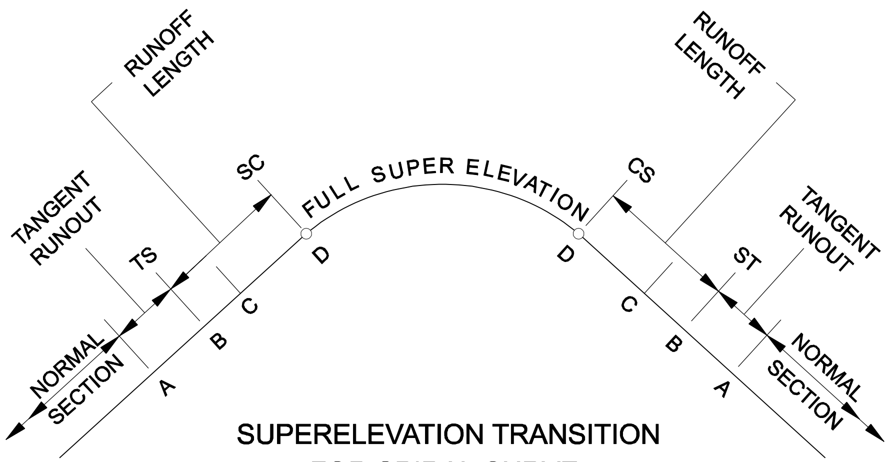
For multilane highways, the tangent runout distance is calculated from Equation 9.3-2, where L is the superelevation runoff distance for multilane highways and all other terms are as defined for Equation 9.3-2. Figure 9.3B presents the tangent runout distances to the nearest hundredth of a meter. This will ensure that the relative longitudinal gradient of the tangent runout equals that of the superelevation runoff.

### 9.3.5.3 Application of Transition Length

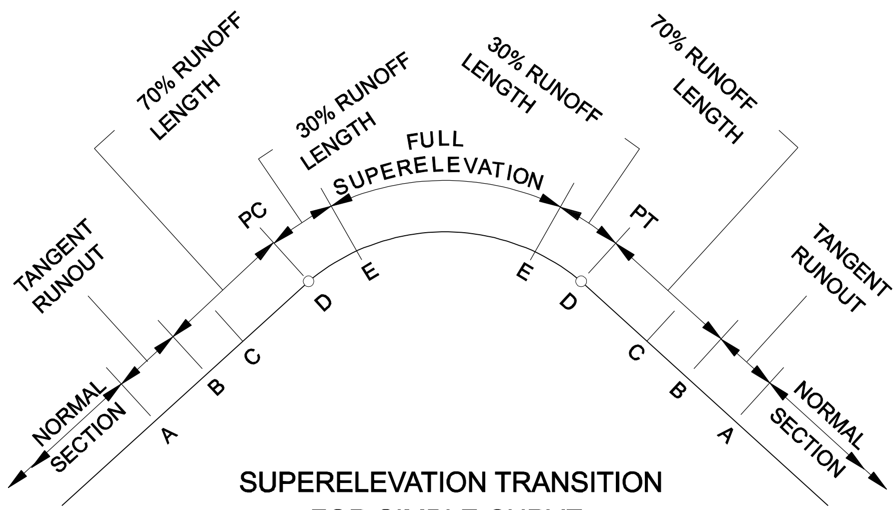
Once the superelevation runoff and tangent runout have been calculated, the designer must determine how to fit the length in the horizontal and vertical planes. Figure 9.3E illustrates the application of the transition length in the plan view. See Section 9.3.11 for illustrations in the profile and cross section views. The following will apply:

1. Spiral Curves. The tangent runout (TR) will be placed on the tangent sections immediately before and after the horizontal curve. The superelevation runoff (L) length will begin at the point of tangent to spiral (TS) and end at the point of spiral to (simple) curve (SC); i.e., the length of the spiral curve is set equal to the superelevation runoff length. The application of L to the end of the curve will be from the CS to the ST.

2. Simple Curves. Typically, 70% of the superelevation runoff length will be placed on the tangent and 30% on the curve. For resurfacing and widening projects, it is acceptable to match the existing distribution of the superelevation runoff between the tangent and curve sections, even if 100% of the runoff length is on the tangent.




SUPERELEVATION TRANSITION
FOR SPIRAL CURVE




SUPERELEVATION TRANSITION
FOR SIMPLE CURVE

*Note: See Section 9.3.11 for profile and cross section views (i.e., A, B, C, D and E) of superelevation development. C is the first (or last) point at which the cross section is at a uniform slope.*

**APPLICATION OF TRANSITION LENGTH**
**(Plan View)**

**Figure 9.3E**

## 9.3.6 Axis of Rotation

The following discusses the axis of rotation for 2-lane, 2-way highways and multilane highways. Section 9.3.11 presents typical figures illustrating the application of the axis of rotation in superelevation development.

### 9.3.6.1 Two-Lane, Two-Way Highways

The axis of rotation will typically be about the inside edge of the traveled way on 2-lane, 2-way highways. This will also apply to a 2-lane highway with an auxiliary lane (e.g., a climbing lane); i.e., for a curve to the right, the axis of rotation is about the line between the climbing lane and the right travel lane.

### 9.3.6.2 Multilane Highways

The following will apply to the axis of rotation for multilane highways:

1. Depressed Median. The axes of rotation will be about the median side of the two inside shoulders.

2. Flush Median/Undivided Facility. The axis of rotation will be about the centerline of the entire roadway section. This also applies to highways with a concrete median barrier (CMB); i.e., the axis of rotation will be about the centerline of the CMB.

3. Raised Median. The axis of rotation will be about the centerline of the entire roadway section; i.e., the center of the raised median.

## 9.3.7 Shoulder Superelevation

### 9.3.7.1 High Side (Outside Shoulder)

On the high side of superelevated sections, the following criteria will apply to the shoulder slope:

1. Typical Application. On most horizontal curves, the high-side shoulder will be rotated concurrently with the adjacent travel lane; i.e., the shoulder and travel lane will remain in a plane section throughout the superelevated curve.

2. Exceptions. Where it is impractical to provide the typical application, the high-side shoulder may be sloped such that the algebraic difference between the shoulder and adjacent travel lane will not exceed 8% (i.e., the superelevation

rollover). This may be necessary, for example, to meet roadside development. This rollover applies to the algebraic difference in cross slopes between the travel lanes and the roadway shoulder. It also applies to lanes which diverge from the mainline, such as ramps. However, it does not apply to approaches.

#### 9.3.7.2 Low Side (Inside Shoulder)

On the low side of a superelevated section, the typical practice is to rotate the finished shoulder concurrently with the adjacent travel lane; i.e., the inside finished shoulder and travel lane will remain in a plane section. The portion of the subgrade from a point below the finished shoulder to the subgrade shoulder point will be designed using a 2.0% slope, regardless of the superelevation rate of the traveled way. See the typical section figures in Section 11.7 for an illustration.

### 9.3.8 Reverse Curves

Reverse curves are two closely spaced horizontal curves with deflections in opposite directions and a short, intervening tangent. For this situation, it may not be practical to achieve a normal crown section between the two curves. A plane section continuously rotating about its axis (i.e., the two inside edges of the traveled way) can be used between the two curves, if they are sufficiently close together. The designer should adhere to the applicable superelevation development criteria (e.g., superelevation transition lengths) for each curve. The following will apply to reverse curves:

1. Normal Section. The designer should not attempt to achieve a normal tangent section between reverse curves unless the normal section can be maintained for a minimum distance of 60 m, and the superelevation transition requirements can be met for both curves.

2. Continuously Rotating Plane. If a normal section is not provided, the pavement will be continuously rotated in a plane about its axis. In this case, the minimum distance between the ST and TS (or PT and PC) will be that needed to meet the superelevation runoff lengths requirements for the two curves. See Figure 9.3L for a schematic of a continuously rotating plane through a reverse curve. Note that, as illustrated in Figure 9.3L, the axis of rotation switches from one inside edge of traveled way to the other inside edge at the point where the roadway becomes level.

### 9.3.9 Broken-Back Curves

Broken-back curves are two closely spaced horizontal curves with deflections in the same direction and a short, intervening tangent. The designer should avoid the use of broken-back curves. Where they must be used, the following will apply to superelevation:

1. Normal Section. The designer should not attempt to achieve a normal tangent section between broken-back curves unless the normal section can be maintained for a minimum distance of 60 m, and the superelevation transition requirements can be met for both curves.

2. Superelevated Section. If a normal section is not provided, the designer should provide a transitional curve-to-curve spiral or a transitional compound curve connection to accommodate the gradual change between superelevation rates.

### 9.3.10 Bridges

From the perspective of the roadway user, a bridge is an integral part of the roadway system and, ideally, horizontal curves and their transitions will be located irrespective of their impact on bridges. However, practical factors in bridge design and bridge construction warrant consideration in the location of horizontal curves at bridges. The following presents, in order from the most desirable to the least desirable, the application of horizontal curves to bridges:

1. The most desirable treatment is to locate the bridge and its approach slabs on a tangent section and sloped at the typical cross slope; i.e., no portion of the curve or its superelevation development will be on the bridge or bridge approach slabs.

2. If a horizontal curve is located on a bridge, any transitions should not be located on the bridge or its approach slabs. This includes both superelevation transitions and spiral transitions. This will result in a uniform cross slope (i.e., the design superelevation rate) and a constant rate of curvature throughout the length of the bridge and bridge approach slabs. This will occur at Section D in Figure 9.3F (spiral curve) and Section E in Figure 9.3G (simple curve).

3. If the superelevation transition is located on the bridge or its approach slabs, the designer should place on the roadway approach that portion of the superelevation development which transitions the roadway cross section from its normal crown to a point where the roadway slopes uniformly. This will occur at Section C in Figure 9.3F (spiral curve) and Section C in Figure 9.3G (simple curve). This will avoid the need to warp the crown on the bridge or the bridge approach slabs.

## 9.3.11 Typical Figures

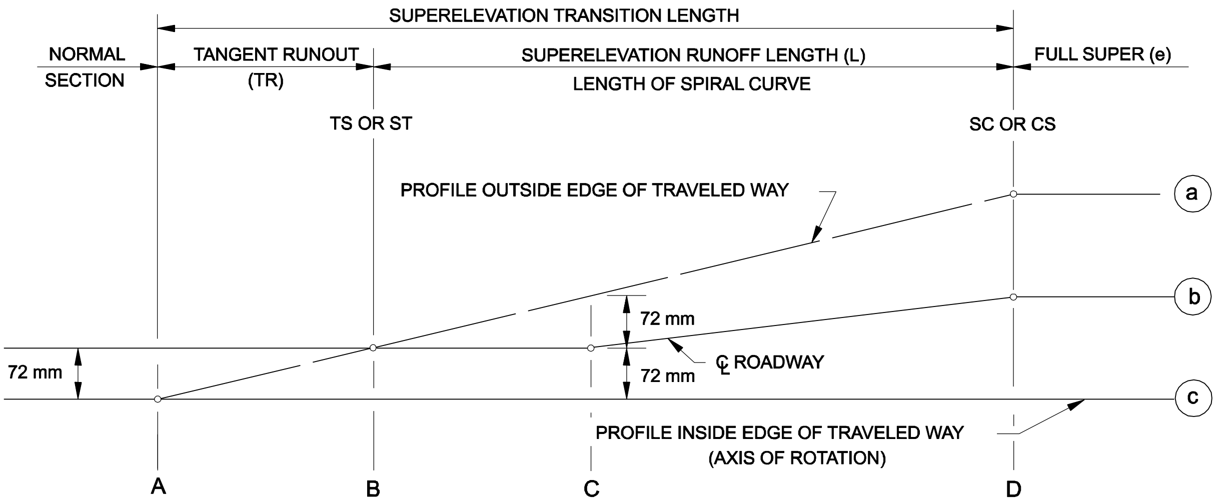
Figures 9.3F through 9.3L present typical figures for superelevation development as follows:

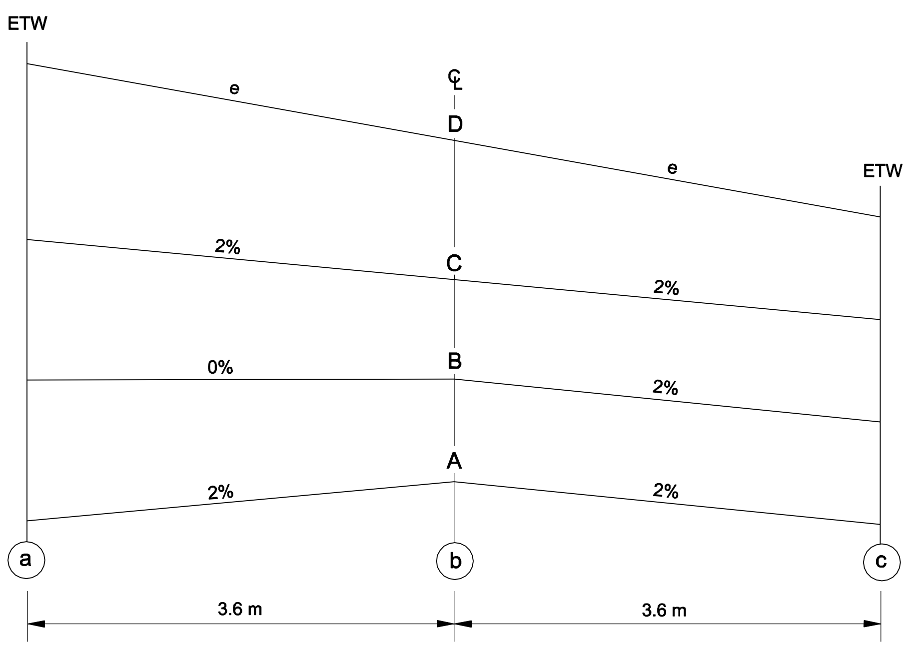
1. Two-Lane Facilities. Figure 9.3F (spiral curve) and Figure 9.3G (simple curve) illustrate the superelevation development with the axis of rotation about the inside edge of traveled way.

2. Multilane Divided Facilities. Figure 9.3H (spiral curve) and Figure 9.3I (simple curve) illustrate the superelevation development with the axes of rotation about the median edges of the two inside shoulders.

3. Other Facilities. Section 9.3.6 identifies several types of facilities where the axis of rotation is about the centerline of the roadway section. Figure 9.3J (spiral curve) and 9.3K (simple curve) illustrate the superelevation development with the axes of rotation about the centerline.

4. Reverse Curves. Figure 9.3L presents a schematic for superelevating reverse curves with a continuously rotating plane (i.e., no normal section).

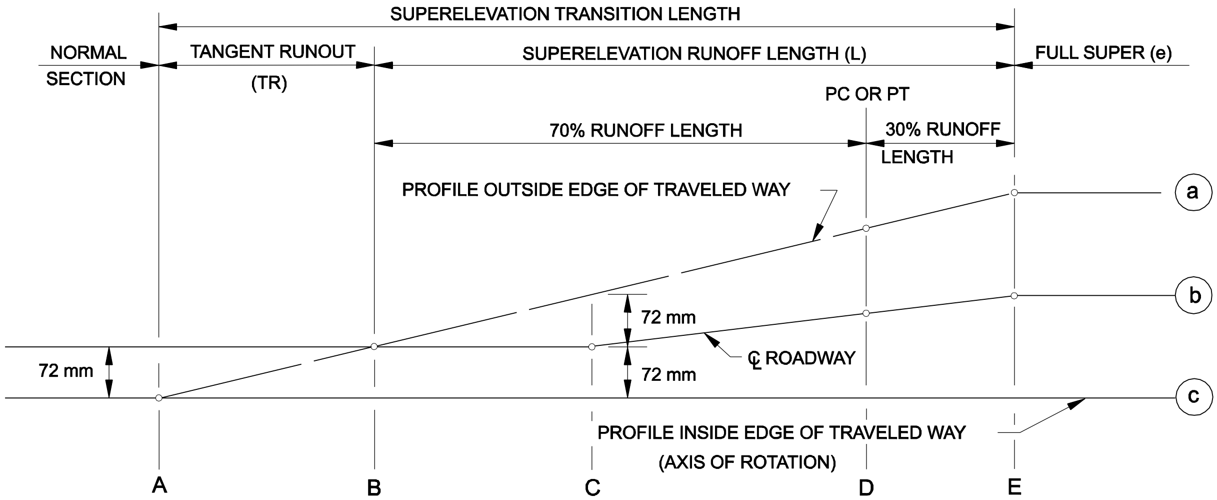


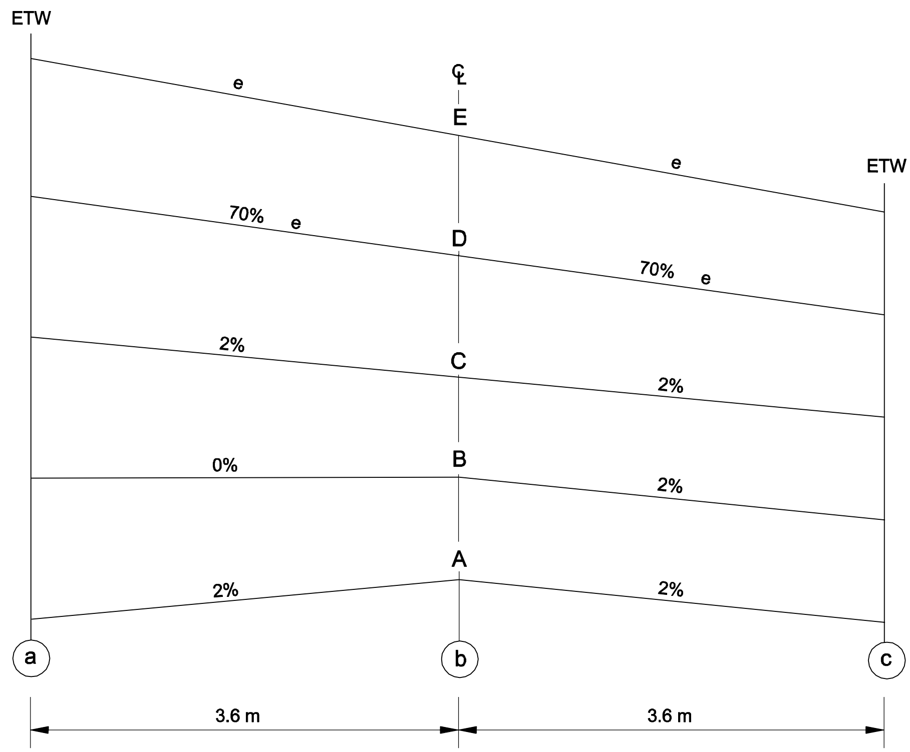




*Note: See Figure 9.3E for plan view.*

**SUPERELEVATION OF TWO-LANE FACILITIES**
**(Spiral Curve)**

**Figure 9.3F**

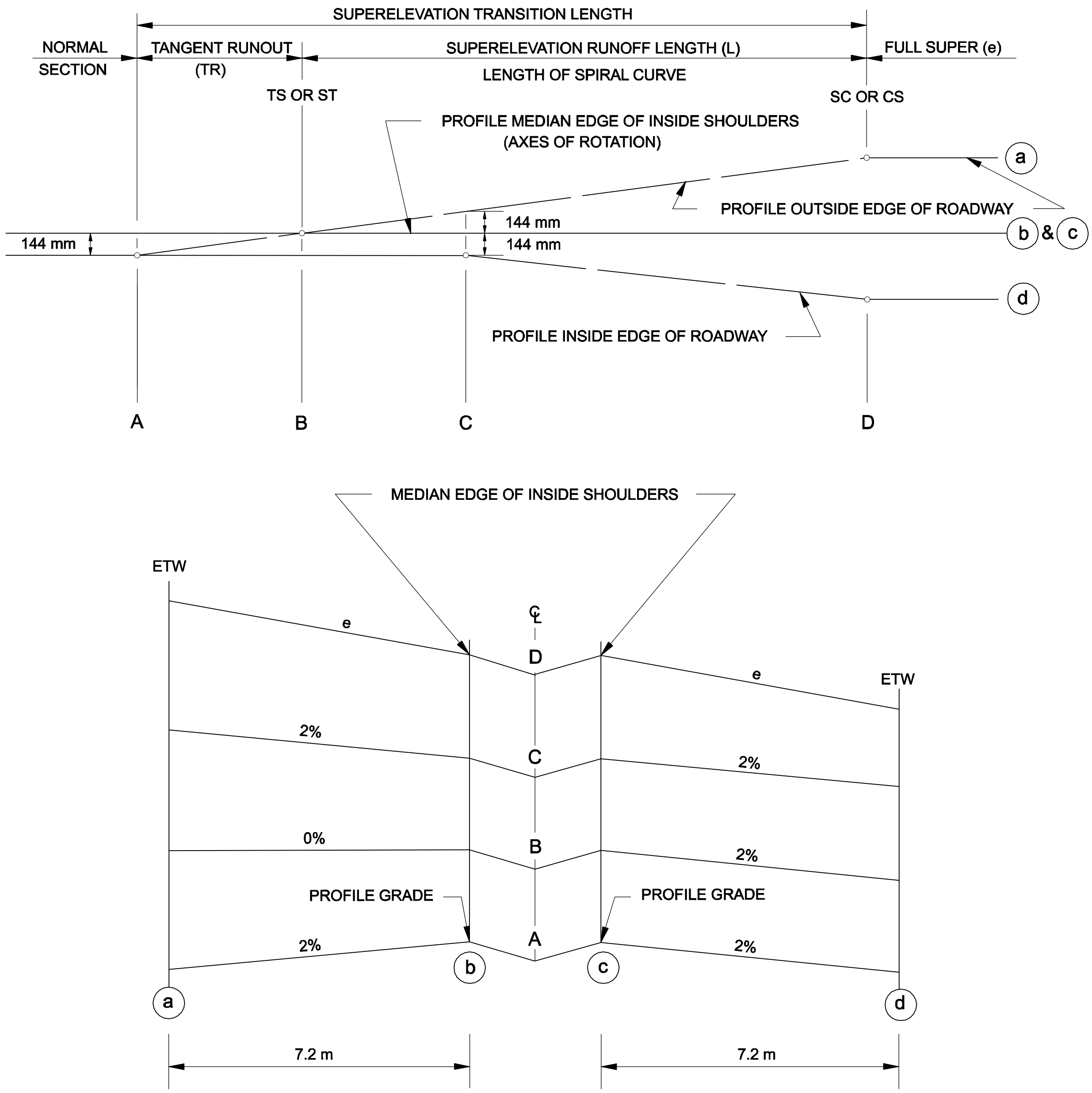



*Note: See Figure 9.3E for plan view.*

**SUPERELEVATION OF TWO-LANE FACILITIES**
**(Simple Curve)**

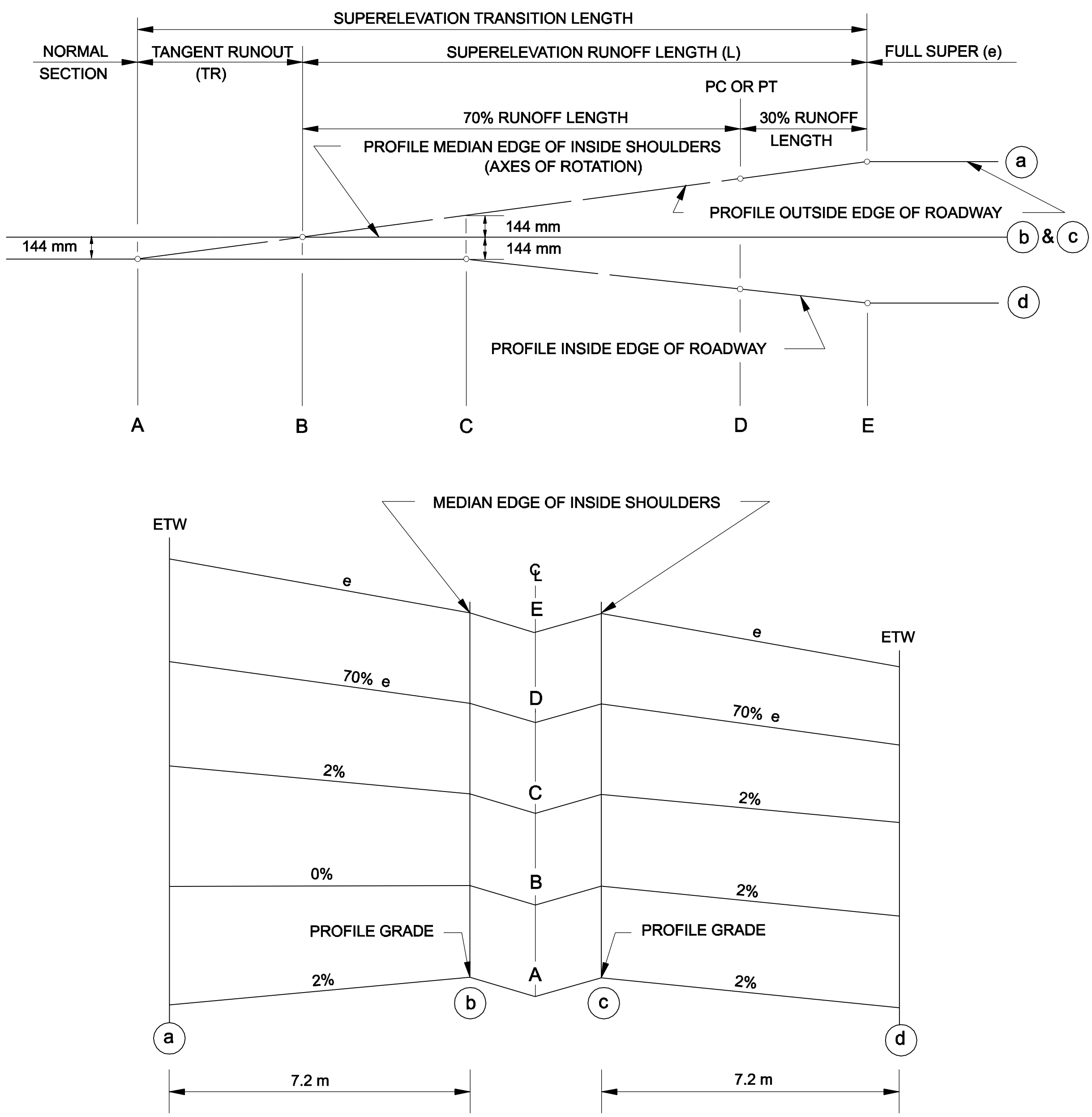
**Figure 9.3G**




*Note: See Figure 9.3E for plan view.*

**SUPERELEVATION OF MULTILANE DIVIDED FACILITIES**
**(Spiral Curve)**

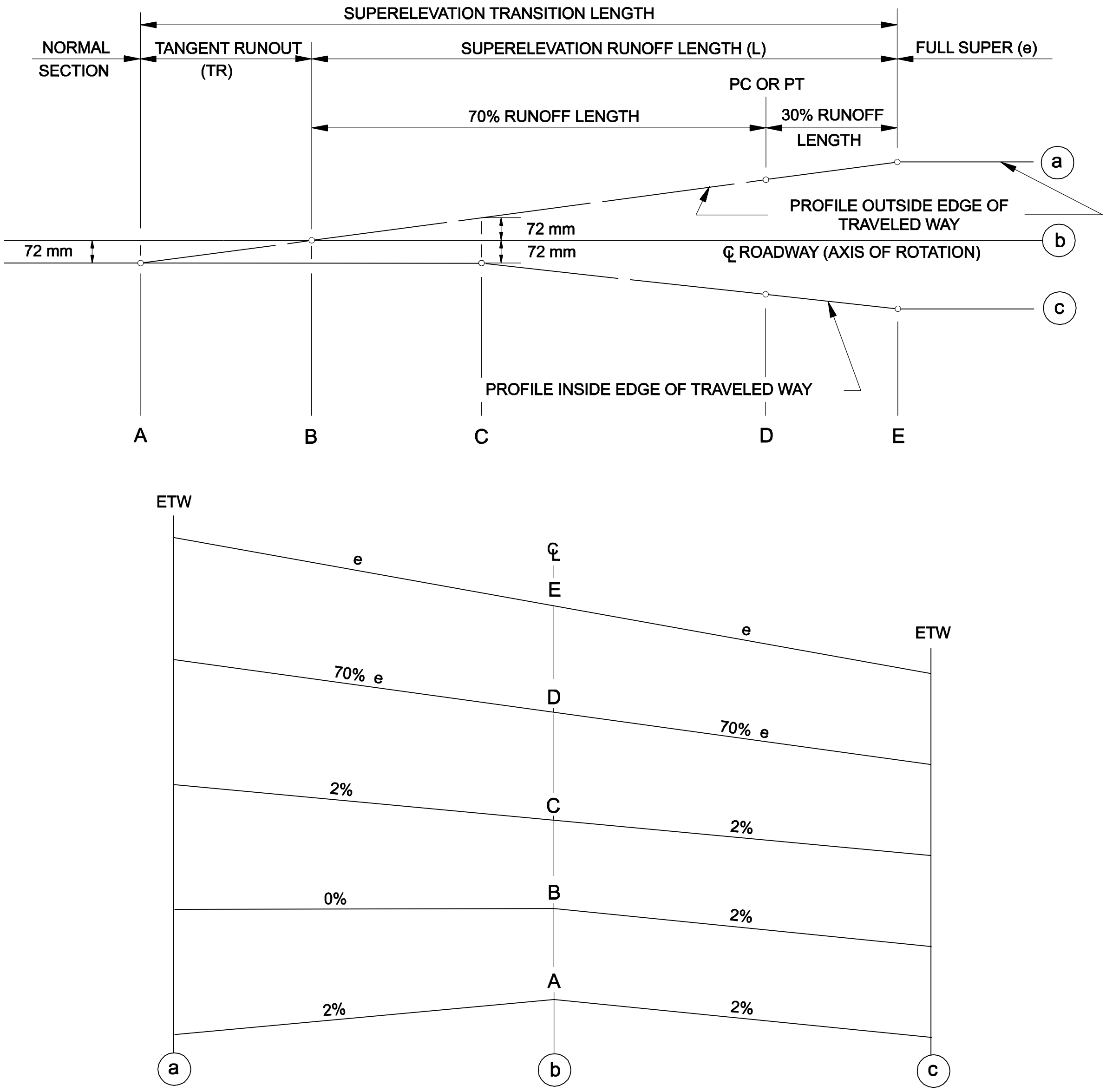
**Figure 9.3H**




*Note: See Figure 9.3E for plan view.*

**SUPERELEVATION OF MULTILANE DIVIDED FACILITIES**
**(Simple Curve)**

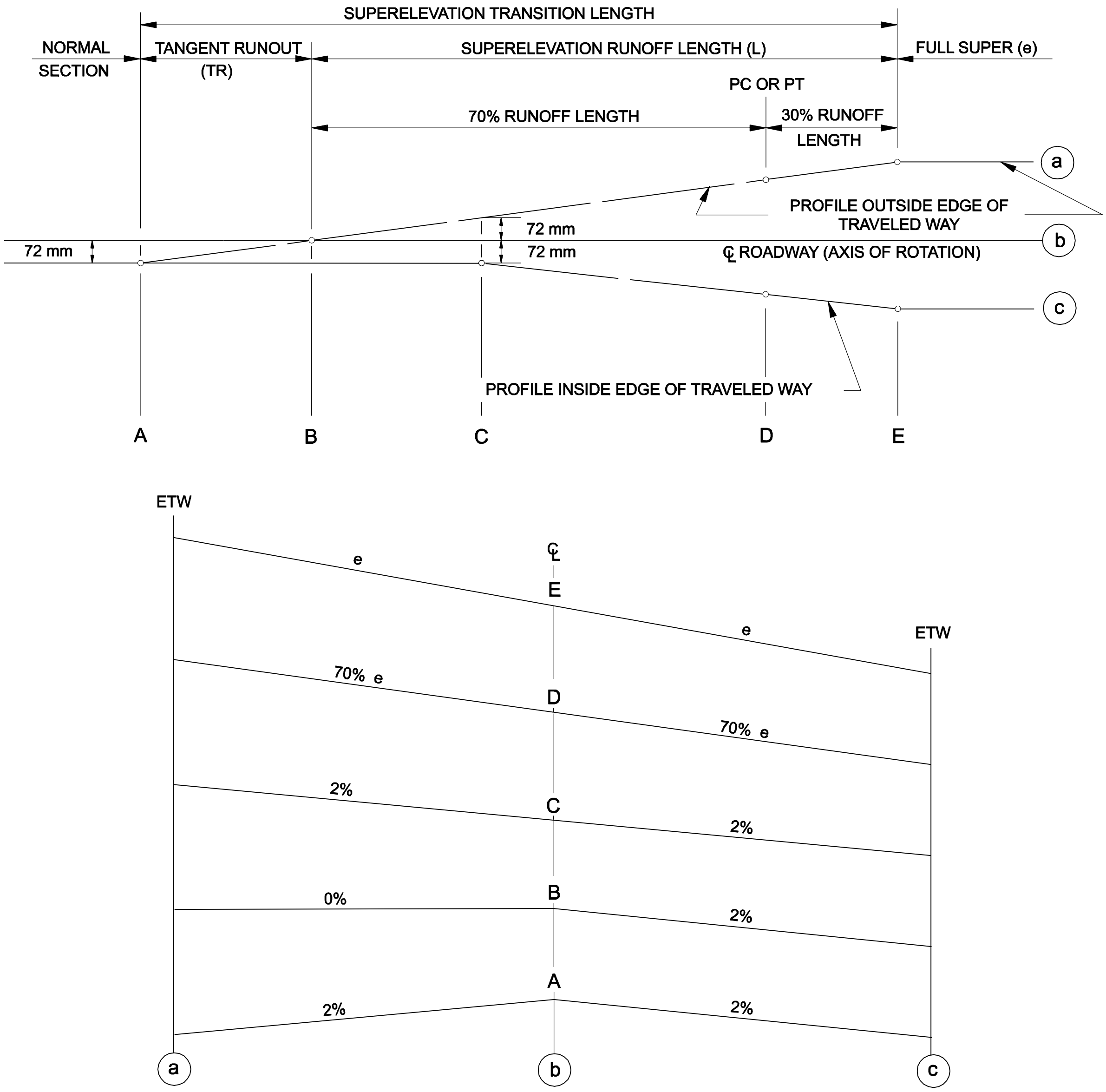
**Figure 9.3I**




*Note: See Figure 9.3E for plan view.*

**AXIS OF ROTATION ABOUT CENTERLINE**
**(Spiral Curve)**

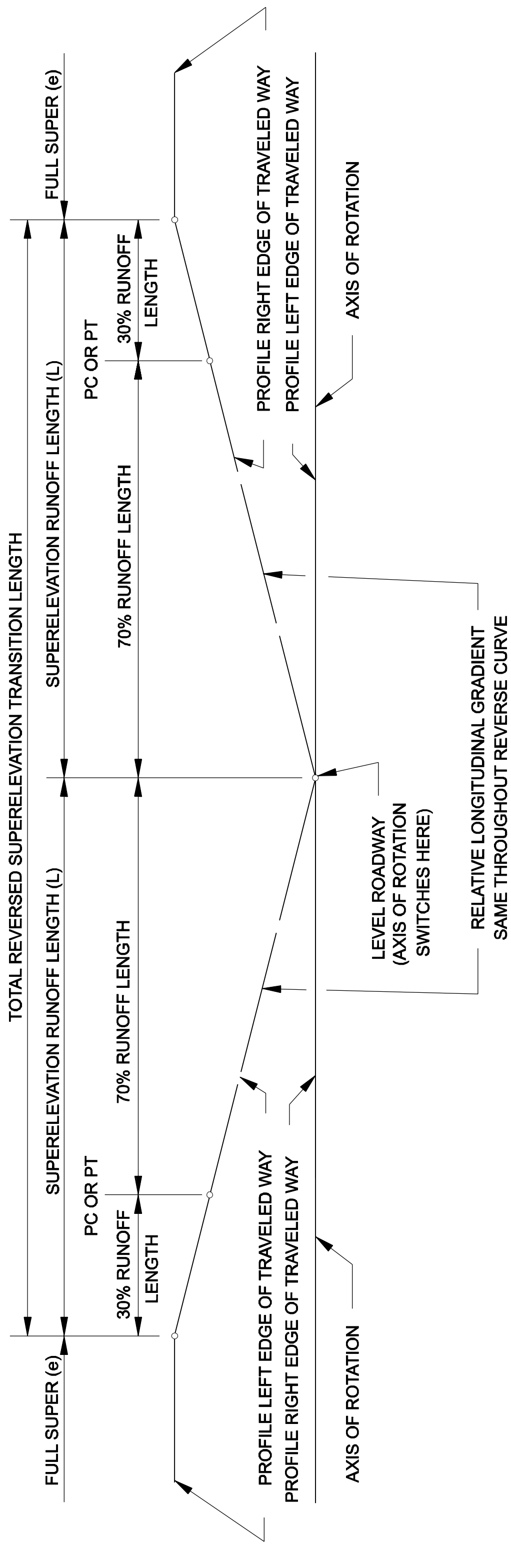
**Figure 9.3J**




*Note: See Figure 9.3E for plan view.*

**AXIS OF ROTATION ABOUT CENTERLINE**
**(Simple Curve)**

**Figure 9.3K**




**SUPERELEVATION OF REVERSE CURVES**
**(Continuously Rotating Plane)**

**Figure 9.3L**

## 9.4 SUPERELEVATION (LOW-SPEED URBAN STREETS)

### 9.4.1.1 General

Low-speed urban street conditions may be used for superelevating streets in urban and urbanized areas where V ≤ 70 km/h. On these facilities, providing superelevation at horizontal curves is frequently impractical because of roadside conditions and, in some cases, may result in undesirable operational conditions. The following lists some of the characteristics of low-speed urban streets which often complicate superelevation development:

1. Roadside Development/Intersections/Driveways. Built-up roadside development is common adjacent to low-speed urban streets. Matching superelevated curves with many driveways, intersections, sidewalks, etc., creates considerable complications. This may also require re-grading parking lots, lawns, etc., to compensate for the higher elevation of the high side of the superelevated curve.

2. Non-Uniform Travel Speeds. On low-speed urban streets, travel speeds are often non-uniform because of frequent signalization, stop signs, vehicular conflicts, etc. It is undesirable for traffic to stop on a superelevated curve, especially when snow or ice is present.

3. Limited Right-of-Way. Superelevating curves often result in more right-of-way impacts than would otherwise be necessary. Right-of-way is often restricted along low-speed urban streets.

4. Wide Pavement Areas. Many low-speed urban streets have wide pavement areas because of high traffic volumes in built-up areas, the absence of a median and the presence of parking lanes. In general, the wider the pavement area, the more complicated will be the development of superelevation.

5. Surface Drainage. Proper pavement drainage on low-speed urban streets can be difficult even on sections with a normal crown. Superelevation introduces another complicating factor.

As discussed in Section 9.2, AASHTO Method 2 is used to distribute superelevation and side friction in determining superelevation rates for the design of horizontal curves on low-speed urban streets. In addition, relatively high side-friction factors are used. The practical impact is that superelevation is rarely warranted on these facilities.

The designer should not apply the superelevation criteria assuming low-speed urban street conditions to highway transitions between rural and urban areas, even if the design speed is $V \leq 70$ km/h. These areas should be designed assuming open-roadway conditions.

### 9.4.2 Superelevation Rates

Based on the selection of $e_{max}$ = 4.0% and the use of AASHTO Method 2 to distribute e and f, Figure 9.4A allows the designer to select the superelevation rate for combinations of curve radii (R) and design speed (V). Note that superelevation rates are a controlling criteria. The designer must seek a design exception for any proposed rate which does not meet the criteria in Figure 9.4A. See Section 8.8 for Department procedures on design exceptions.

### 9.4.3 Minimum Radii Without Superelevation

On low-speed urban streets, horizontal curves with sufficiently large radii do not require superelevation; i.e., the normal crown section can be maintained around a curve. The threshold exists where the theoretical superelevation equals -2.0%. Figure 9.4A indicates limiting radii for normal crown (NC).

### 9.4.4 Transition Length

As defined in Section 9.3.1, the superelevation transition length is the distance required to transition the roadway from a normal crown section to the full design superelevation. The superelevation transition length is the sum of the tangent runout distance (TR) and superelevation runoff length (L).

#### 9.4.4.1 Two-Lane Roadways

Superelevation Runoff

Figure 9.4A presents the superelevation runoff lengths for 2-lane roadways for various combinations of superelevation rates and design speed. The lengths are calculated as follows:

| e | V = 30 km/h | | | | | V = 40 km/h | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | R(m) | Trans. Length (Two-Lane) | | Trans. Length (Multilane) | | R(m) | Trans. Length (Two-Lane) | | Trans. Length (Multilane) | |
| | | L(m) | TR(m) | L(m) | TR(m) | | L(m) | TR(m) | L(m) | TR(m) |
| NC | R ≥ 25 | 0 | 0 | 0 | 0 | R ≥ 55 | 0 | 0 | 0 | 0 |
| 2.0% | 25 > R ≥ 22 | 10 | 10.00 | 15 | 15.00 | 55 > R ≥ 47 | 15 | 15.00 | 15 | 15.00 |
| 3.0% | 22 > R ≥ 21 | 15 | 10.00 | 20 | 13.33 | 47 > R ≥ 46 | 15 | 10.00 | 20 | 13.33 |
| 4.0% | 21 > R ≥ 20 | 20 | 10.00 | 25 | 12.50 | 46 > R ≥ 45 | 20 | 10.00 | 25 | 12.50 |
| | $R_{min}$ = 20 m | | | | | $R_{min}$ = 45 m | | | | |

| e | V = 50 km/h | | | | | V = 60 km/h | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | R(m) | Trans. Length (Two-Lane) | | Trans. Length (Multilane) | | R(m) | Trans. Length (Two-Lane) | | Trans. Length (Multilane) | |
| | | L(m) | TR(m) | L(m) | TR(m) | | L(m) | TR(m) | L(m) | TR(m) |
| NC | R ≥ 104 | 0 | 0 | 0 | 0 | R ≥ 178 | 0 | 0 | 0 | 0 |
| 2.0% | 104 > R ≥ 86 | 15 | 15.00 | 15 | 15.00 | 178 > R ≥ 142 | 20 | 20.00 | 20 | 20.00 |
| 3.0% | 86 > R ≥ 83 | 15 | 10.00 | 25 | 16.67 | 142 > R ≥ 135 | 20 | 13.33 | 25 | 16.67 |
| 4.0% | 83 > R ≥ 80 | 20 | 10.00 | 30 | 15.00 | 135 > R ≥ 125 | 20 | 10.00 | 30 | 15.00 |
| | $R_{min}$ = 80 m | | | | | $R_{min}$ = 125 m | | | | |

| e | V = 70 km/h | | | | |
|---|---|---|---|---|---|
| | R(m) | Trans. Length (Two-Lane) | | Trans. Length (Multilane) | |
| | | L(m) | TR(m) | L(m) | TR(m) |
| NC | R ≥ 258 | 0 | 0 | 0 | 0 |
| 2.0% | 258 > R ≥ 204 | 20 | 20.00 | 20 | 20.00 |
| 3.0% | 204 > R ≥ 193 | 20 | 13.33 | 25 | 16.67 |
| 4.0% | 193 > R ≥ 190 | 25 | 12.50 | 35 | 17.50 |
| | $R_{min}$ = 190 m | | | | |

$e_{max}$ = 4.0%

Key:

R = Radius of curve, m
V = Design speed, km/h
e = Superelevation rate, %
L = Minimum length of superelevation runoff (from adverse slope removed to full super), m
TR = Tangent runout from NC to adverse slope removed, m
NC = Normal crown = 2.0%

**RATE OF SUPERELEVATION AND MINIMUM LENGTH OF TRANSITION (Low-Speed Urban Streets)**

**Figure 9.4A**

$L = e \times W \times RS \geq L_{min}$ (Equation 9.4-1)

where:

L = Superelevation runoff length for a 2-lane roadway, m

W = Width of travel lane (assumed to be 3.6 m)

RS = Reciprocal of relative longitudinal slope between the roadway centerline and outside edge of the traveled way (see Figure 9.4B)

e = Superelevation rate, decimal

$L_{min}$ = Minimum superelevation runoff length regardless of calculated L (see Figure 9.4C), m

The calculated L values are subject to minimum lengths ($L_{min}$), which are based on approximately one second of travel time. Note that, where the calculated numbers apply, L has been rounded up to the next highest 5 m increment in Figure 9.4A.

Tangent Runout

Figure 9.4A presents the tangent runout distances for 2-lane roadways. For roadways with a normal crown other than 2%, use Equation 9.4-2 to compute the tangent runout distance. The distance is calculated as follows:

$$TR = \frac{S_{NORMAL}}{e / L} = \frac{(S_{NORMAL})(L)}{e}$$ (Equation 9.4-2)

where:

$TR$ = Tangent runout distance for a 2-lane roadway, m

$S_{NORMAL}$ = Travel lane cross slope on tangent (typically 2.0%), decimal

$e$ = Design superelevation rate (i.e., full superelevation for horizontal curve), decimal

$L$ = Superelevation runoff length for a 2-lane roadway, m (Equation 9.4-1)

| Design Speed(km/h) | RS | Maximum Relative Longitudinal Slope, G(%)* |
|---|---|---|
| 30 | 105 | 0.98 |
| 40 | 115 | 0.90 |
| 50 | 125 | 0.80 |
| 60 | 135 | 0.74 |
| 70 | 150 | 0.68 |

* G(%) = 1/RS x 100

**MAXIMUM RELATIVE LONGITUDINAL SLOPES**
**(Low-Speed Urban Streets)**

**Figure 9.4B**

| Design Speed(km/h) | Minimum Superelevation Runoff Lengths (m) |
|---|---|
| 30 | 10 |
| 40 | 15 |
| 50 | 15 |
| 60 | 20 |
| 70 | 20 |

MINIMUM SUPERELEVATION
RUNOFF LENGTHS ($L_{min}$)
(Low-Speed Urban Streets)

Figure 9.4C

The values in Figure 9.4A are presented to the nearest hundredth of a meter. This will ensure that the relative longitudinal gradient of the tangent runout equals that of the superelevation runoff.

#### 9.4.4.2 Multilane Highways

Superelevation Runoff

The superelevation runoff distance for multilane highways is calculated by:

$$L = 1.5 \times e \times W \times RS \geq L_{min} \qquad \text{(Equation 9.4-3)}$$

where the terms are as defined for Equation 9.4-1 for 2-lane highways. The calculated runoff lengths for multilane facilities are 1.5 times those for 2-lane facilities. The longer lengths are more appropriate for major facilities considering higher traffic volumes and the desire to provide a higher level of driver comfort.

Figure 9.4A presents the superelevation runoff distances for multilane facilities which are either the $L_{min}$ values (Figure 9.4C) or the calculated values (Equation 9.4-3) rounded up to the next highest 5 m increment.

Tangent Runout

For multilane highways, the tangent runout distance is calculated from Equation 9.4-2, where L is the superelevation runoff distance for multilane highways and all other terms are as defined for Equation 9.4-2. Figure 9.4A presents the tangent runout distances to the nearest hundredth of a meter. This will ensure that the relative longitudinal gradient of the tangent runout equals that of the superelevation runoff.

#### 9.4.4.3 Application of Transition Length

The criteria presented in Section 9.3 for open-roadway conditions will also apply to low-speed urban streets.

### 9.4.5 Axis of Rotation

On low-speed urban streets, the axis of rotation is typically about the centerline of the traveled way. This means, for example, if on-street parking is present on one side, the axis of rotation will not be in the center of the roadway section.

Low-speed urban streets may also present special cases because of the presence of two-way, left-turn lanes; turning lanes at intersections; etc.  For these, where superelevated, the axis of rotation will be determined on a case-by-case basis.

### 9.4.6 Shoulder Superelevation

The criteria in Section 9.3 for open-roadway conditions will also apply to low-speed urban streets.

## 9.5 HORIZONTAL SIGHT DISTANCE

### 9.5.1 Sight Obstruction (Definition)

Sight obstructions on the inside of a horizontal curve are defined as obstacles which interfere with the line of sight on a continuous basis. These include walls, cut slopes, wooded areas, buildings and high farm crops. In general, point obstacles such as traffic signs and utility poles are not considered sight obstructions on the inside of horizontal curves. The designer must examine each curve individually to determine whether it is necessary to remove an obstruction or to adjust the horizontal alignment to obtain the required sight distance.

### 9.5.2 Middle Ordinate

The needed clearance on the inside of the horizontal curve is calculated as follows:

$$M = R\left(1 - COS\left(\frac{90° \cdot S}{\pi \cdot R}\right)\right)$$ (Equation 9.5-1

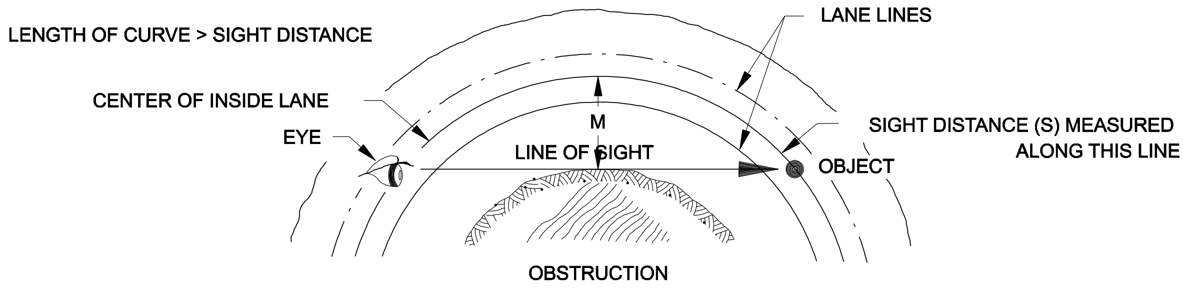
Where:

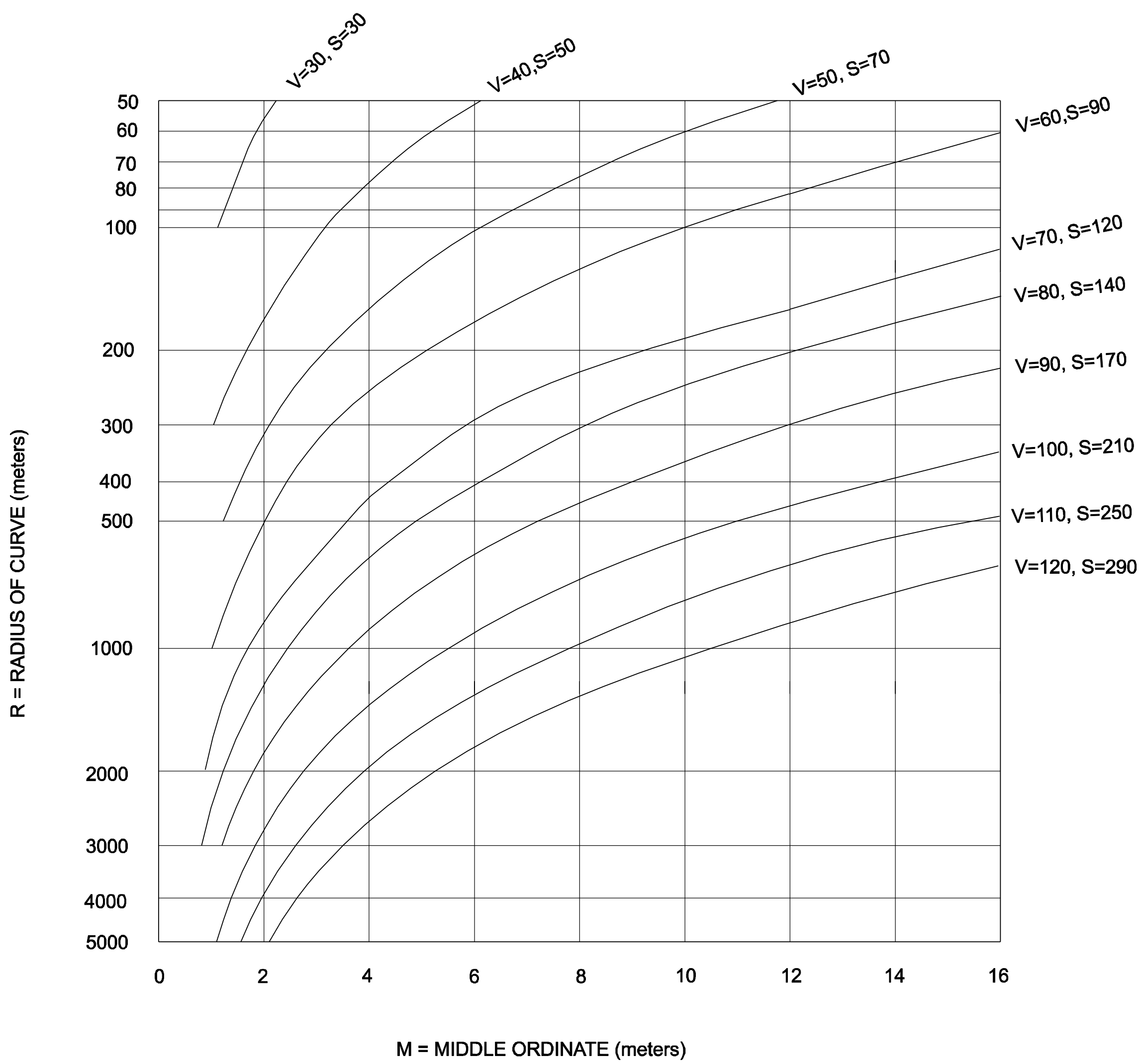
| | | |
|---|---|---|
| $M$ | = | Middle ordinate, or distance from the center of the inside travel lane to the obstruction, m |
| $R$ | = | Radius of curve, m |
| $S$ | = | Stopping sight distance, m |

Note: The expression $\left(\frac{90° \cdot S}{\pi \cdot R}\right)$ is in degrees, not radians.

At a minimum, SSD will be available throughout the horizontal curve. Figures 9.5A and 9.5B provide the horizontal clearance criteria (i.e., the middle ordinate) for various combinations of desirable and minimum stopping sight distances and curve radii. For those selections of S which fall outside of the figures (i.e., M > 16 m and/or R < 50 m), the designer should use Equation 9.5-1 to calculate the needed clearance.

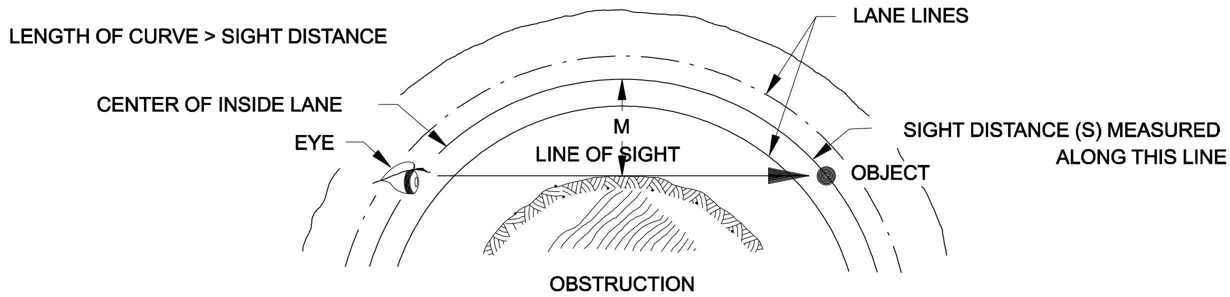
The Example on Figure 9.5C illustrates the determination of clearance requirements at a horizontal curve based on SSD.

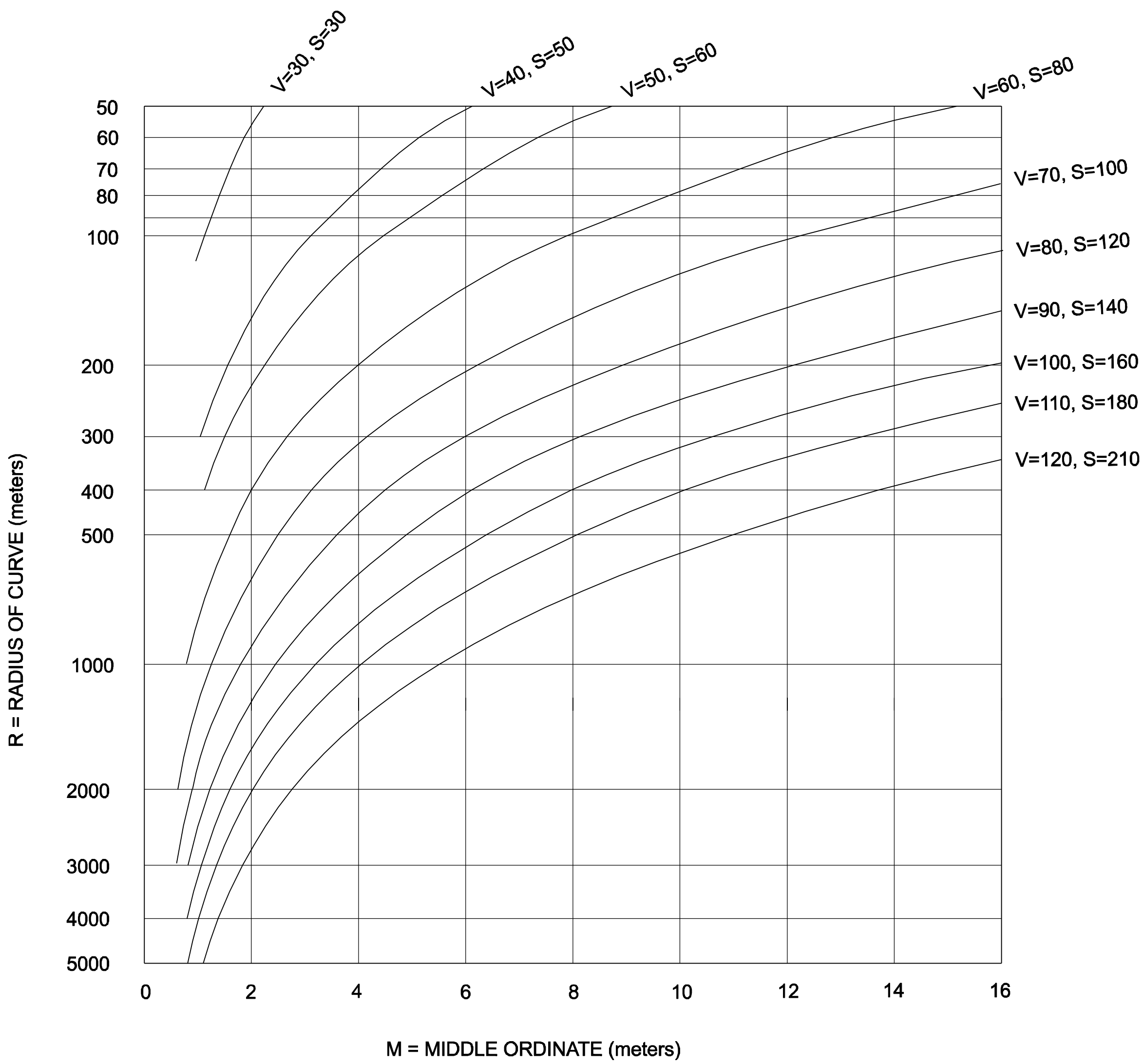



**SIGHT DISTANCE AT HORIZONTAL CURVES**
**(Desirable SSD)**

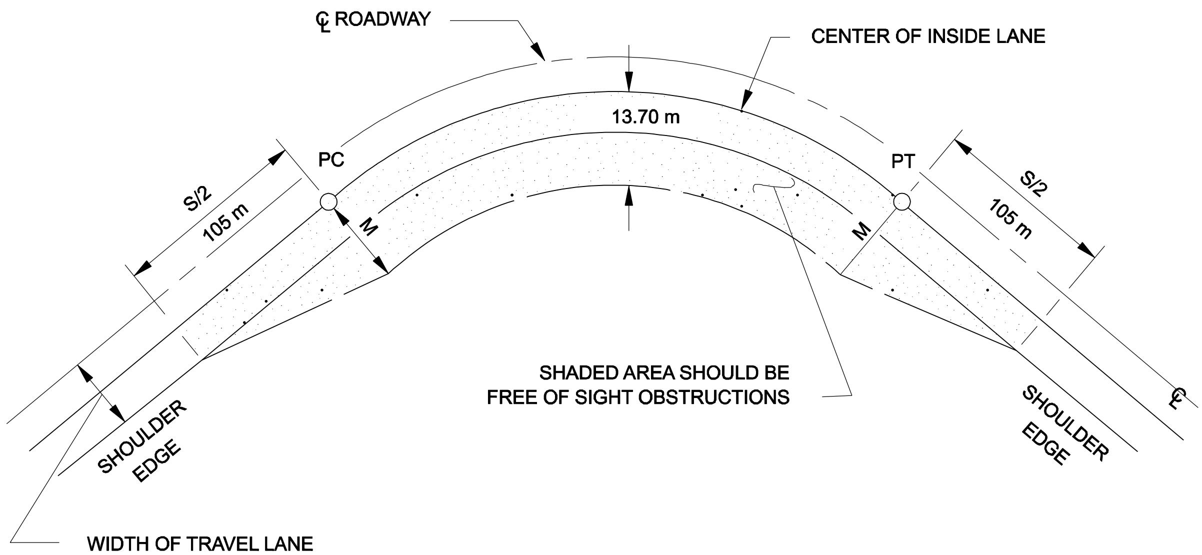
**Figure 9.5A**




**SIGHT DISTANCE AT HORIZONTAL CURVES**
**(Minimum SSD)**

**Figure 9.5B**




**Example 9.5-1**

Given: Design Speed = 100 km/h

R = 400 m

Problem: Determine the horizontal clearance requirements for the horizontal curve using the desirable SSD value.

Solution: Figure 8.6A yields a SSD = 210.0 m. Using Equation 9.5-1 for horizontal clearance:

$$M = R\left(1 - \cos\left(\frac{90° \cdot S}{\pi \cdot R}\right)\right)$$

$$M = 400\left(1 - \cos\left(\frac{(90°)(205)}{(\pi)(400)}\right)\right) = 13.70 \text{ m}$$

The above figure also illustrates the horizontal clearance requirements for the entering and exiting portion of the horizontal curve. Note that, using Figure 9.5A, the middle ordinate would read approximately 13.5 m.

**SIGHT CLEARANCE REQUIREMENTS FOR HORIZONTAL CURVES**
**(Example Problem)**

**Figure 9.5C**

### 9.5.3 Entering/Exiting Portions

The M values from Figures 9.5A and 9.5B apply between the PC and PT of the horizontal curve (or from the SC to the CS). In addition, some transition is needed on the entering and exiting portions of the curve. The designer should typically use the following steps:

Step 1: Locate the point which is on the outside edge of shoulder and a distance of S/2 before the PC or SC.

Step 2: Locate the point which is a distance M measured laterally from the center of the inside travel lane at the PC or SC.

Step 3: Connect the two points located in Step #'s 1 and 2. The area between this line and the roadway should be clear of all continuous sight obstructions.

Step 4: A symmetrical application of Step #'s 1 through 3 should be used beyond the PT or CS.

The Example on Figure 9.5C illustrates the determination of clearance requirements entering and exiting from a simple curve.

### 9.5.4 Application

For application, the height of eye is 1070 mm and the height of object is 150 mm. Both the eye and object are assumed to be in the center of the inside travel lane. In the elevation view, the line-of-sight intercept with the obstruction is at the midpoint of the sightline and 600 mm above the center of the inside lane.

### 9.5.5 Longitudinal Barriers

Longitudinal barriers (e.g., bridge rails, guardrail, CMB) can cause sight distance restrictions at horizontal curves, because barriers are placed relatively close to the traveled way (often 3 m or less) and because their height is greater than 600 mm. The designer should check the line of sight over a barrier along a horizontal curve and attempt to locate the barrier such that it does not block the line of sight. The following should also be considered:

1. Superelevation. A superelevated roadway will elevate the driver eye and improve the line of sight over the barrier.

2. Grades. The line of sight over a barrier may be improved for a driver on an upgrade and lessened on a downgrade.

3. Barrier Height. The higher the barrier, the more obstructive it will be to the line of sight.

4. Object Height. Because of the typical heights of barriers, there may be many sites where the barrier blocks visibility to a 150 mm object but does not block the view of a 460 mm object, the typical height of vehicular taillights. This observation provides some perspective to the potential safety problem at the site.

Each barrier location on a horizontal curve will require an individual analysis to determine its impacts on the line of sight. The designer must determine the elevation of the driver eye, the elevation of the object (150 mm above the pavement surface) and the elevation of the barrier where the line of sight intercepts the barrier run. If the barrier does block the line of sight to a 150 mm object, the designer should consider relocating the barrier or revising the horizontal alignment.

## 9.6 COMPUTATION OF HORIZONTAL CURVES

### 9.6.1 Spiral Curves

Special Note: *The computation of the spiral curve is dependent on one of two publications:*

- Transition Curves for Highways*, Public Roads Administration (Joseph Barnett)*; and
- Oregon Standard Highway Spiral*, Oregon Department of Transportation.*

*As of the publication of the* Montana Road Design Manual, *neither of these two publications had been converted to metric. However, Table II in* Transition Curves for Highways *by Barnett can be used to determine the necessary values for the calculation of the spiral transition information.*

The following presents typical figures for computing a spiral curve:

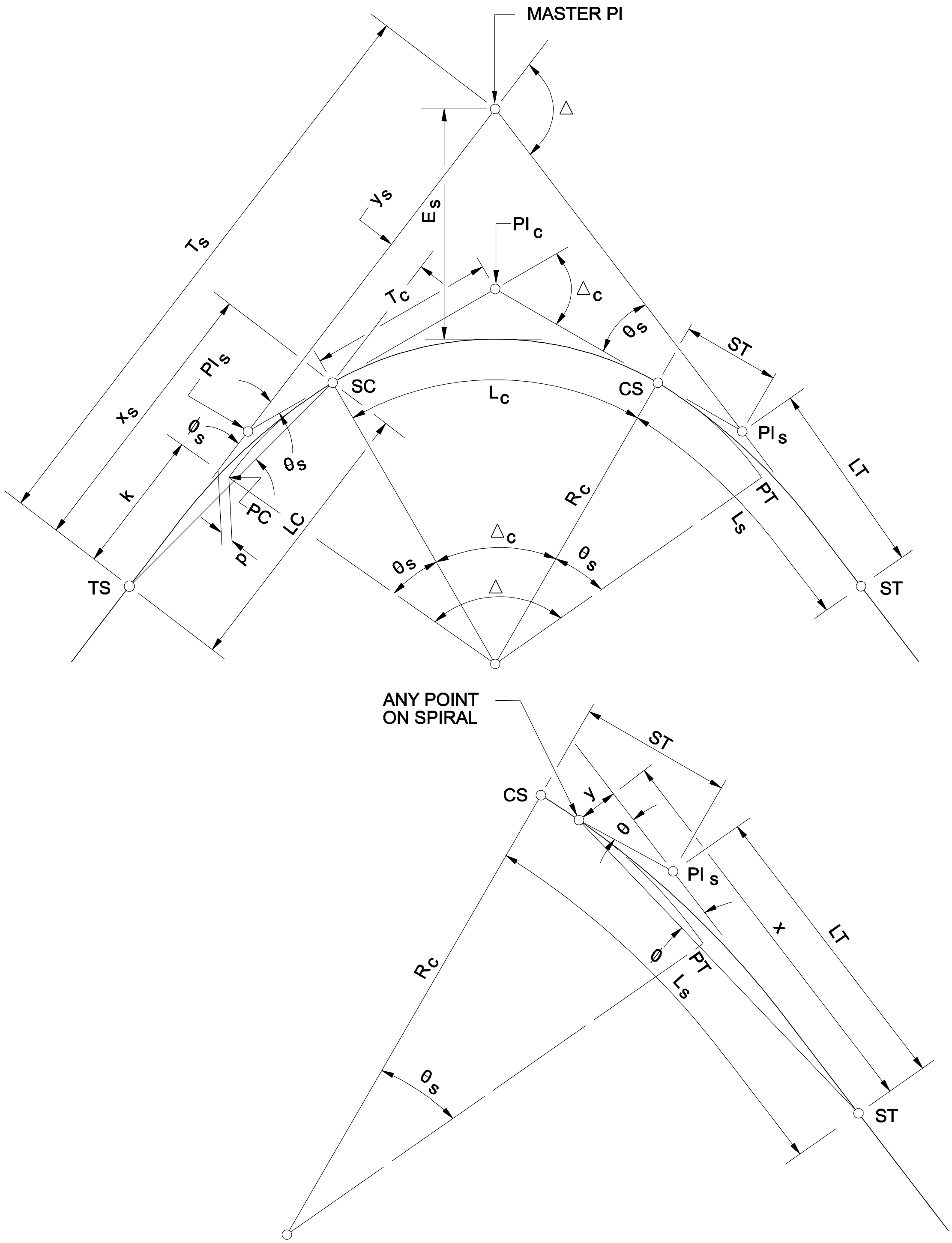
1. Figure 9.6A illustrates the key elements of a spiral curve.
2. Figure 9.6B presents definitions for the spiral curve nomenclature on Figure 9.6A.
3. Figure 9.6C presents equations for computing a spiral curve.

Typically, the known data will be the station of the Master PI, the deflection angle ($\Delta$) and the radius of the circular curve ($R_C$) in meters. As discussed in Section 9.3, the length of the spiral curve ($L_S$) will be set equal to the length of the superelevation runoff (Figures 9.3A and 9.3B). Based on the values of $\Delta$, $L_S$ and $R_C$, $\theta_s$ can be calculated as indicated in Figure 9.6C, and the p and k values can be read from Table II in *Transition Curves for Highways* by Joseph Barnett. The tangent length ($T_s$), the external distance ($E_s$) and the remaining spiral curve data can be computed as described in Figure 9.6C. Example 9.6-1 illustrates the computation of a spiral curve.

The following steps are used to determine the locations of the TS, SC, CS and ST:

1. PI station - $T_s$ = TS station
2. TS station + Ls = SC station
3. SC station + Lc = CS station
4. CS station + Ls = ST station

Figures 9.6A, 9.6B and 9.6C are consistent with the Barnett spiral publication. It is also acceptable to use the data from the *Oregon Standard Highway Spiral* to compute a spiral curve.




*Note: See Figure 9.6B for definition of terms.*

**SPIRAL CURVE ELEMENTS**

**Figure 9.6A**

## SPIRAL TRANSITION CURVE NOMENCLATURE

| | | |
|---|---|---|
| Master PI | = | Point of intersection of the main tangents. |
| PC | = | Point at which the circular curve extended becomes parallel to the line from TS to the Master PI. |
| PT | = | Point at which the circular curve extended becomes parallel to the line from ST to the Master PI. |
| $PI_c$ | = | Point of intersection of circular curve tangents. |
| $PI_s$ | = | Point of intersection of the main tangent and tangent of circular curve. |
| TS | = | Tangent to spiral; common point of spiral and near transition. |
| SC | = | Spiral to curve; common point of spiral and circular curve of near transition. |
| CS | = | Curve to spiral; common point of circular curve and spiral of far transition. |
| ST | = | Spiral to tangent; common point of spiral and tangent of far transition. |
| $R_c$ | = | Radius of the circular curve (SC to CS), m |
| $L_s$ | = | Length of spiral, m |
| $L_c$ | = | Length of circular curve, m |
| $T_s$ | = | Tangent distance Master PI to TS or ST, m |
| $T_c$ | = | Tangent distance from SC or CS to $PI_c$, m |
| $E_s$ | = | External distance Master PI to midpoint of circular curve, m |
| LT | = | Long tangent of spiral only, m |
| ST | = | Short tangent of spiral only, m |
| LC | = | Long chord of spiral, m. |
| p | = | Offset distance from the main tangent to the PC or PT of the circular curve produced, m |
| k | = | Distance from TS to point on main tangent opposite the PC of the circular curve produced, m |
| $\Delta$ | = | Total deflection angle between main tangents of the entire curve, degrees |
| $\Delta_c$ | = | Deflection angle between tangents at the SC and the CS or the central angle of the circular curve, degrees |
| $\theta_s$ | = | Central angle between the tangent of the complete curve and the tangent at the SC; i.e., the “spiral angle,” degrees |
| $\varphi_s$ | = | Spiral deflection angle from tangents at TS to SC or from ST to SC, degrees |
| $x_s y_s$ | = | Coordinates of SC from the TS or of CS from ST. |
| L | = | Length of spiral arc from the TS or ST to any point on the spiral, m |
| x,y | = | Coordinates to any point on the spiral from TS or ST. |
| $\varphi$ | = | Spiral deflection angle from TS or ST to any point on spiral, degrees |
| $\theta$ | = | The central angle of spiral arc L to any point on the spiral, degrees. $\theta$ equals $\theta_s$ when L equals $L_s$. Note that the $\theta$ referred to in Table II of *Transition Curves for Highways* is actually $\theta_s$. |

**SPIRAL CURVE NOMENCLATURE**

**Figure 9.6B**

## CURVE FUNCTIONS

1. $\theta_S = (L_s / R_C)(90/\pi)$
2. $\Delta_C = \Delta - 2\theta_S$
3. $L_C = \frac{\Delta_C}{360} 2\pi R_C$
4. $T_S = (R_C + p)tan(\Delta/2) + k$
5. $E_S = (R_C + p)(1/cos(\Delta/2) - 1) + p = \left[\frac{(R_C + p)}{cos(\Delta/2)} - (R_C + p)\right] + p$
6. p and k are obtained from *Transition Curves for Highways* by Barnett.

## SPIRAL FUNCTIONS

| Correction for C in Formula : $\varphi = \frac{\theta}{3} - C$ | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $\theta_S$ in Degrees | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
| C in Minute | 0.2 | 0.4 | 0.8 | 1.4 | 2.2 | 3.4 | 4.8 | 6.6 |

7. $\varphi(approx.) = \frac{\theta}{3}$ *if* $\theta_S < 15°00'$
8. $\varphi(approx.) = \frac{\theta}{3} - C,$ *if* $\theta_S \geq 15°00'$
9. $\varphi = \frac{\theta_S}{3}\left[\frac{L}{L_S}\right]^2$
10. Exact value of $\varphi$ by coordinates

$$tan\,\varphi = \frac{y}{x}$$

11 $ST = \frac{y_S}{\sin\theta_S}$

12. $LT = x_S - \left(\frac{y_S}{tan\,\theta_S}\right)$
13. $LC = \frac{x_s}{cos\,\varphi_S}$
14. $x_S = LC\,cos\,\varphi_S$
15. $y_S = LC\,sin\,\varphi_S$
16. $\theta = \frac{L^2}{{L_S}^2}\theta_2$
17. $x = L\left(1 - \frac{\theta^2}{10} + \frac{\theta^4}{216} - \frac{\theta^6}{9360} + \frac{\theta^8}{685440}\right)^*$
18. $y = L\left(\frac{\theta}{3} + \frac{\theta^3}{42} + \frac{\theta^5}{1320} - \frac{\theta^7}{75600} + \frac{\theta^9}{6894720}\right)^*$

* $\theta$ *is in radians for equations 17 and 18 only*.

Note : These equations are based on *Transitions Curves for Highways* by Barnett.

**SPIRAL CURVE FORMULAS**

**Figure 9.6C**

* * * * * * * * * *

**Example 9.6-1**

(1) Given: Rural Two-Lane State Highway

Design Speed = 100 km/h
$\Delta$ = 15°00′00″ Right
(Master) PI Station = 43 + 16.63
$R_C$ = 900 m

Problem: If warranted, determine the curve data for the spiral curve.

Solution: The following steps apply:

Step 1: From Section 9.2.2, a spiral curve is warranted on a rural State highway where $R \leq 1165$ m. Therefore, use a spiral curve.

Step 2: The length of the spiral curve is set equal to the superelevation runoff ($L_s$) length. From Figure 9.3A, $L_s$ = 60 m for V = 100 km/h and $R_C$ = 900 m.

Step 3: From the equations in Figure 9.6C, calculate the curve functions as follows:

1. $\theta_S = (L_s / R_C)(90/\pi) = (60/900)(90/\pi)$
   $\theta_S = 1.9098°...$
   $\theta_S = 1°54'35"$ (rounded value)

2. $\Delta_C = \Delta - 2\theta_S = (15°0'0'') - (3°49'10'')$
   $\Delta_C = 11°10'50" = 11.1805°$

3. $L_C = \frac{\Delta_C}{360} 2\pi R_C = \frac{11.18}{360}(2\pi)(900)$
   $L_C = 175.6237\text{m}$
   $L_C = 175.62\text{m}$ (rounded value)

4.* $T_S = (R_C + p)\tan(\Delta/2) + k$

5.* $E_S = (R_C + p)(1/\cos(\Delta/2) - 1) + p$

* For Equations 4 and 5, obtain the values for p and k from Table II of *Transition Curves for Highways*:

$p = 0.00278380$ $k = 0.49998$

Note that these values are for a unit spiral length. To obtain the actual values for p and k, multiply by $L_s$ (60 m):

$p = (0.00278380)(60) = 0.1670$ m
$k = (0.49998)(60) = 29.9988$ m

Therefore:

$T_s = (900 + 0.167) \tan(15/2) + 29.9988$
$T_s = 148.5080$ m
$T_s = 148.51$ m (rounded value)
$E_s = (900 + 0.167)(1/\cos(15/2) - 1) + 0.167$
$E_s = 7.9345$ m
$E_s = 7.93$ m (rounded value)

Step 4: Determine the Stations for TS, SC, CS and ST:

TS Station = PI Station - $T_s$ = 43 + 16.63 - 148.51 = 41 + 68.12
SC Station = TS Station + $L_s$ = 41 + 68.12 + 60 = 42 + 28.12
CS Station = SC Station + $L_c$ = 42 + 28.12 + 175.62 = 44 + 03.74
ST Station = CS Station + $L_s$ = 44 + 03.74 + 60 = 44 + 63.74

* * * * * * * * * *

### 9.6.2 <u>Simple Curves</u>

The following presents typical figures for computing a simple curve:

1. Figure 9.6D illustrates the key elements of a simple curve.

2. Figure 9.6E presents definitions for the simple curve nomenclature on Figure 9.6D.

Typically, the known data will be the station of the PI, the deflection angle ($\Delta$) and the radius of the simple curve (R). The remaining curve data must be computed. Example 9.6-2 illustrates a sample calculation.

* * * * * * * * * *

**Example 9.6-2**

Given: $\Delta = 7°00'00''$
R = 1300 m
PI Station = 22 + 34.58

Problem: Assuming the use of a simple curve, determine the curve data.

Solution: Use the equations from Figure 9.6E as follows:

1. $T = R(tan(\Delta / 2)) = 1300(tan(7/2))$

   $T = 79.5144m$

   $T = 79.51m$ (rounded value)

2. $L = \frac{\Delta}{360} 2\pi R = \frac{7}{360}(2\pi)(1300)$

   $L = 158.82496m$

   $L = 158.82m$ (rounded value)

3. $E = \frac{R}{cos(\Delta/2)} - R = \frac{1300}{cos(7/2)} - 1300$

   $E = 2.4292m$

   $E = 2.43m$ (rounded value)

4. $LC = 2R(sin(\Delta/2)) = (2)(1300)(sin 7/2))$

   $LC = 158.7262m$

   $LC = 158.73m$ (rounded value)

5. $M = R(1 - cos(\Delta/2)) = 1300(1 - cos(7/2))$

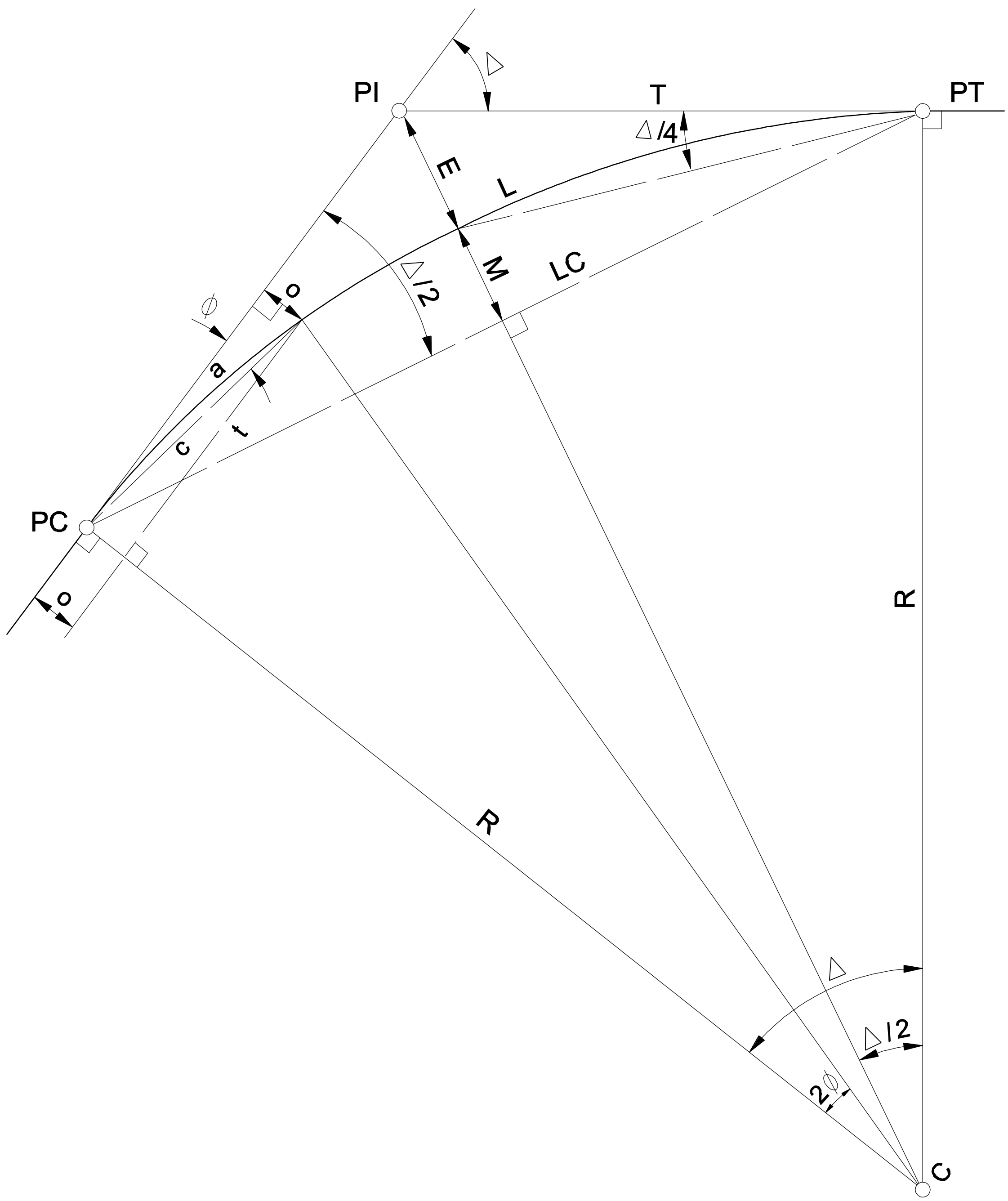
   $M = 2.4247m$

   $M = 2.42m$ (rounded value)

6. Stations are as follows:

   Station PC = Station PI - T = 22 + 34.58 - 79.51 = 21 + 55.07
   Station PT = Station PC + L = 21 + 55.07 + 158.82 = 23 + 13.89

* * * * * * * * * *




**SIMPLE CURVE ELEMENTS**

**Figure 9.6D**

## CURVE SYMBOLS

| | | |
|---|---|---|
| $\Delta$ | = | Deflection angle, degrees |
| T | = | Tangent distance, m. T = distance from PC to PI or distance from PI to PT |
| L | = | Length of curve, m. L = distance from PC to PT along curve |
| R | = | Radius of curvature, m |
| E | = | External distance (PI to mid-point of curve), m |
| C | = | Intersection of radii at center of circular arc |
| LC | = | Length of long chord (PC to PT), m |
| M | = | Middle ordinate (mid-point of arc to mid-point of long chord), m |
| *a* | = | Length of arc to any point on a curve, m |
| c | = | Length of chord from PC to any point on curve, m |
| $\varphi$ | = | Deflection angle from tangent to any point on curve, degrees |
| t | = | Distance along tangent from PC to any point on curve, m |
| o | = | Tangent offset to any point on curve, m |

## CURVE FORMULA

$$T = R(\tan(\Delta/2)) = R\,\frac{\sin(\Delta/2)}{\cos(\Delta/2)}$$

$$L = \frac{\Delta}{360}\,2\pi R$$

$$E = \frac{R}{\cos(\Delta/2)} - R = T\,\tan(\Delta/4)$$

$$LC = 2R(\sin(\Delta/2)) = 2T(\cos\Delta/2)$$

$$M = R(1 - \cos(\Delta/2)) = E\cos(\Delta/2)$$

$$a = \frac{(200\varphi)(2\pi R)}{100(360)} = \frac{(\varphi)(\pi R)}{90}$$

$$c = 2R\left(\sin\frac{(100)(360a)}{(200)(2\pi R)}\right) = 2R\,(\sin\frac{90a}{\pi R})$$

$$\varphi = \frac{90a}{(\varphi)(\pi R)}$$

$$\cos\varphi = (R - o)/2R$$

$$t = R\sin 2\varphi = (c)\cos\varphi$$

$$o = (c)\sin\varphi$$

$$o = R - \sqrt{R^2 - t^2}$$

$$o = R - (R\cos 2\varphi)$$

$$o = R(1 - \cos 2\varphi)$$

$$\pi = 3.141592654$$

## CIRCULAR CURVE ABBREVIATIONS

| | | |
|---|---|---|
| PC | = | Point of Curvature (Beginning of Curve) |
| PT | = | Point of Tangency (End of Curve) |
| PI | = | Point of Intersection of Tangents |
| PRC | = | Point of Reverse Curvature |
| PCC | = | Point of Compound Curvature |

## LOCATING THE PC AND PT

Station PC = Station PI – T
Station PT = Station PC + L
Stations are in 100 meters. For example, Sta 13+54.86 means 1354.86 meters from Sta 0+00.

**SIMPLE CURVE NOMENCLATURE/FORMULAS**

**Figure 9.6E**

### 9.6.3 Compound Curves

Figure 9.6F illustrates the key elements of a symmetrical, 3-centered compound curve. It also presents the equations to compute the curve elements assuming that the following are known:

1. $\Delta$, the deflection angle;
2. p, the offset between the interior curve (extended) to a point where it becomes parallel with the tangent line;
3. $R_1$, the radius of the flatter entering and exiting curve; and
4. $R_2$, the radius of the sharper, interior curve.

Example 9.6-3 illustrates a sample computation for a 3-centered, symmetrical compound curve.

* * * * * * * * * * 

**Example 9.6-3**

Given: $\Delta = 90°$
$R_1 = 55$ m
$R_2 = 18$ m
p = 2.5 m

Problem: Determine the curve data for the compound curve.

Solution: Use the equations from Figure 9.6F as follows:

1. $T_1 = (R_2 + p)\tan(\Delta/2) = (18 + 2.5)\tan(90/2)$

$T_1 = 20.50\text{m}$

2. $\Delta_1 = \cos^{-1}\left[\frac{R_1 - R_2 - p}{R_1 - R_2}\right] = \cos^{-1}\left[\frac{55 - 18 - 2.5}{55 - 18}\right]$

$\Delta_1 = 21.18287...°$

$\Delta_1 = 21°10'58''$ (rounded value)

3. $T = T_1 + (R_1 - R_2)\sin\Delta_1 = 20.50 + (55 - 18)\sin(21°10'58'')$

$T = 33.8697...m$

$T = 33.87m$ (rounded value)

4. $T_2 = T_1 - R_2 \sin \Delta_1 = 20.50 - (18)\sin(21°10'58")$

$T_2 = 13.9958...m$

$T_2 = 14.00m$ (rounded value)

5. $E = \dfrac{R_2 + p}{\cos(\Delta / 2)} - R_2 = \dfrac{18 + 2.5}{\cos(90 / 2)} - 18$

$E = 10.9913...m$

$E = 10.99m$ (rounded value)

6. $M = R_1 - \left[R_2 \cos(\Delta / 2 - \Delta_1)\right] = 18 - ((18)\cos(90 / 2 - 21°10'58"))$

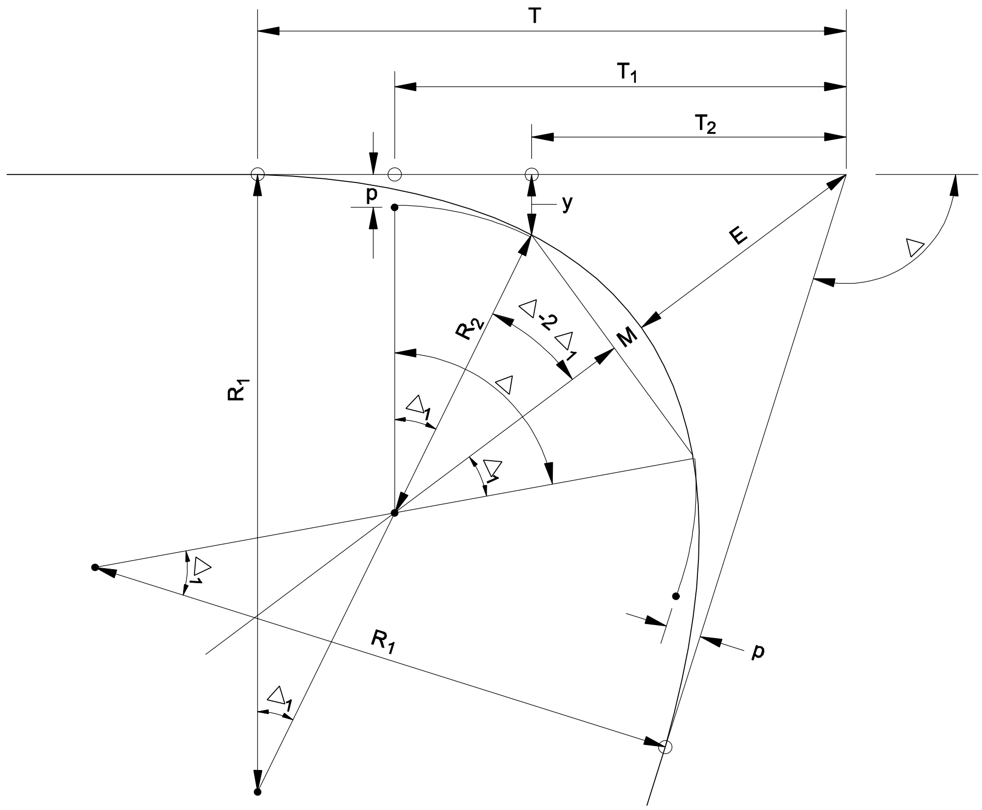
$M = 1.5329...m$

$M = 1.53m$ (rounded value)

7. $y = (R_2 + p) - R_2 \cos \Delta_1 = (18 + 2.5) - (18)\cos(21°10'58")$

$y = 3.7162...m$

$y = 3.72m$ (rounded value)




## CURVE FORMULA

1. $T_1 = (R_2 + p)\tan\frac{\Delta}{2}$

2. $\Delta_1 = \cos^{-1}\left[\frac{R_1 - R_2 - p}{R_1 - R_2}\right]$

3. $T = T_1 + (R_1 - R_2)\sin\Delta_1$

4. $T_2 = T_1 - R_2 \sin\Delta_1$

5. $E = \frac{R_2 + p}{\cos(\Delta/2)} - R_2$

6. $M = R_1 - \left[R_2 \cos(\Delta/2 - \Delta_1)\right]$

7. $y = (R_2 + p) - R_2 \cos\Delta_1$

*Note: "p" is the offset location between the interior curve (extended) to a point where it becomes parallel with the tangent line. See Figure 9.6E for other circular curve nomenclature.*

**COMPOUND CURVE ELEMENTS/FORMULAS**

**Figure 9.6F**

## 9.6.4 Rounding of Curve Data

### 9.6.4.1 New Horizontal Curve

The following summarizes Department practices for presenting data for a new horizontal curve on the roadway plans:

1. Deflection Angle. These should be recorded in degrees rounded to the nearest second of a degree.

2. Linear Distances. These should be recorded in meters rounded to the nearest one hundredth of a meter (i.e., two decimal places).

3. Curve Radii. Normally, curve radii will be selected from those in Figure 9.2C. Where rounding is necessary, radii should be recorded in meters rounded to the nearest 5 meters.

When using computer-generated curve data, the designer must consider the implications of rounding off the data according to the above criteria. To ensure mathematical consistency, the following procedure should be used when defining the horizontal alignment in Geopak:

Given: Horizontal alignment defined with PI coordinates from survey data or design.

Input:

1. Store given PI coordinates.

2. Inverse PI coordinates to produce distance and bearing between PIs.

3. Round distance to two places (0.01). Round bearings to nearest second (01”).

4.

    a. Define the horizontal alignment by traversing PI to PI using the rounded distance and bearing.

    b. Set station preference to two places (0.01).

    c. Set distance preference to four places (0.0001).

Output:

5.

a. Rounded bearings to nearest second (to be shown on plans).

b. Rounded control point stations to two places (to be shown on plans).

c. Adjusted control point coordinates to four places (to be shown on coordinate table).

d. Curve data to four places that must be rounded to two places before placing on plans. Round T, L and E by hand computations using the rounded D and R as shown on the plans. Minor adjustments to the control point stations may be necessary to reflect the rounded curved data.

* * * * * * * * * *

Example 9.6-4

Given: GEOPAK SPIRAL CURVE DATA OUTPUT

*Note: GEOPAK spiral curve nomenclature does not match exactly the nomenclature in Figures 25.6A through 25.6C.*

| | | | |
|---|---|---|---|
| PISCS | CG2 N30,530.4772 | E30,526.8770 | STA 202+63.64 |

| | | |
|---|---|---|
| Total Tangent | = | 239.6145 |
| Total Length | = | 471.8148 |
| Total Delta | = | 26°13'01.00" (LT) |
| Back Tangent | = | N 72°51'14.00" E |
| Ahead Tangent | = | N 46°38'13.00" E |

Spiral Back (Spiral CG2B) Type 1 Spiral Element

| | | |
|---|---|---|
| Angle = 1°54'35.49" (LT) | P = 0.1667 | BK = N 72°51'14.00" E |
| LS = 60.0000 | K = 29.9989 | AH = N 70°56'38.50" E |
| R = 900.0000 | LT = 40.0023 | Defl = 0°38'11.81" |
| YS = 0.6666 | ST = 20.0021 | Deg = 6°21'58.31" |
| XS = 59.9933 | LC = 59.9970 | |
| A = 232.3790 | | |

Spiral Coordinates

| Point | North | East | Station |
|---|---|---|---|
| TS | 30,459.8366 | 30,297.9119 | 200+24.03 |

| | | | |
|---|---|---|---|
| PI | 30,471.6296 | 30,336.1363 | 200+64.03 |
| SC | 30,478.1602 | 30,355.0423 | 200+84.03 |
| CC | 31,328.8402 | 30,061.1998 | |

Circular Section Curve Data

Curve CG2

| | | | | |
|---|---|---|---|---|
| P.I. Station | = | 202+62.21 | N30,536.3351 | E30,523.4601 |
| Delta | = | 22°23'50.01"(LT) | | |
| Tangent | = | 178.1822 | | |
| Length | = | 351.8148 | | |
| Radius | = | 900.0000 | | |
| External | = | 17.4687 | | |
| Long Chord | = | 349.5791 | | |
| Mid. Ord. | = | 17.1361 | | |
| P.C. Station | | 200+84.03 | N30,478.1602 | E30,355.0423 |
| P.T. Station | | 204+35.84 | N30,654.2932 | E30,657.0071 |
| C.C. | | | N31,328.8402 | E30,061.1998 |
| Back | = | N 70°56'38.50" E | | |
| Ahead | = | N 48°32'48.49" E | | |
| Chord Bearing | = | N 59°44'43.50" E | | |

Spiral Ahead (Spiral CG2A) Type 2 Spiral Element

| | | | | | |
|---|---|---|---|---|---|
| Angle | = 1°54'35.49" (LT) | P | = 0.1667 | BK | = N 48°32'48.49" E |
| LS | = 60.0000 | K | = 29.9989 | AH | = N46°38'13.00" E |
| R | = 900.0000 | LT | = 40.0023 | Defl | = 0°38'11.81" |
| YS | = 0.6666 | ST | = 20.0021 | Deg | = 6°21'58.31" |
| XS | = 59.9933 | LC | = 59.9970 | | |
| A | = 232.3790 | | | | |

Spiral Coordinates

| Point | North | East | Station |
|---|---|---|---|
| CS | 30,654.2932 | 30,657.0071 | 204+35.84 |
| PI | 30,667.5347 | 30,671.9986 | 204+55.84 |
| ST | 30,695.0011 | 30,701.0810 | 204+95.84 |
| CC | 31,328.8402 | 30,061.1998 | |

Problem: Recompute curve data manually to produce rounded values to be shown on the plans.

Solution: Hold Geopak values for P.I. Station, Δ, RC and LS.

$$\theta_S = \frac{90 \cdot 60}{\pi \cdot 900} = 1.90985...^\circ = 1^\circ 54'35.49'' \rightarrow 1^\circ 54'35''$$

$$\Delta_C = 26^\circ 13'01'' - (2)1^\circ 54'35'' = 26.21694^\circ - 3.81944^\circ = 22.39750^\circ = 22^\circ 23'51.0'' \rightarrow 22^\circ 23'51''$$

$$L_C = \frac{22^\circ 23'51''}{360} 2\pi 900 = 351.819 \rightarrow 351.82\text{m}$$

$$T_s = (900 + p)\tan \Delta / 2 = k$$

Use p and k found in Barnett's (p = 0.1670, k = 29.9988)

$$T_S = (900 + .01670)\tan \frac{26^\circ 13''01''}{2} + 29.9988 = 239.61\text{m}$$

| | | |
|---|---|---|
| 202+63.64 - 239.61 = | 200+24.03 | TS |
| | +60 | |
| | 200+84.03 | SC |
| | +351.82 | |
| | 204+35.85 | CS |
| | +60 | |
| | 204+95.85 | ST |

*Note: Geopak currently does not have the capability to round curve data and at the same time produce coordinates to four places. Therefore, coordinates listed in the coordinate table for PC, PT, TS, SC, CS, ST will differ slightly from coordinates computed using the rounded curve data shown on the plans.*

### 9.6.4.2 Existing Horizontal Curves

For existing horizontal curves, the Department's rounding practices for presentation on the roadway plans are:

1. Deflection Angle. These should be recorded in degrees rounded to the nearest second of a degree.

2. Linear Distances. These should be recorded in meters rounded to the nearest one hundredth of a meter (i.e., two decimal places).

3. Curve Radii. Rounding will be determined by the Project Scope of Work as follows:

a. Overlay and Widening. Where an existing horizontal curve will be retained in the project, the designer will calculate the metric radius from the known radius and round to three decimal places. The T and L distances are then calculated based on the metric radius and rounded to the nearest 0.01 of a meter. See Example 9.6-5.

b. Reconstruction. Where the alignment for a reconstruction project will approximate the existing alignment, normally the curve radii will be selected from those in Figure 9.2C. Where this is not practical, the radii of the reconstructed curve may be rounded to the nearest 5 meters. The T and L distances are then calculated based on the metric radius and rounded to the nearest 0.01 of a meter. See Example 9.6-6.

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**Example 9.6-5**

Given: An existing horizontal curve has the following data in English units:

PI Sta = 302+68.57
Δ = 12°30'
R = 4583.66' (D=1°15')
T = 501.99'
L = 1000.00'

Problem: For an overlay and widening project and assuming the curve will be retained as is, determine the proper metric dimensions for the horizontal curve.

Solution: The metric data are:

PI Sta = 92+9.86
Δ = 12°30'
R = 1397.010 m
T = 153.00 m
L = 304.78 m

Example 9.6-6

Given: An existing horizontal curve has the following data in English units:

PI Sta = 302+68.57
$\Delta$ = 12°30'
R = 4583.66' (D=1°15')
T = 501.99'
L = 1000.00'

Problem: For a reconstruction project and assuming the curve will be reconstructed, determine the proper metric dimensions for the horizontal curve.

Solution: The metric data are:

PI Sta = 92+9.86
$\Delta$ = 12°30'
R = 1400 m
T = 153.32 m
L = 305.43 m

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### 9.6.5 **Stationing and Bearings**

The following will apply to projects where control points are used to establish horizontal alignment:

1. Rounding. All stationing will be rounded to the nearest hundredth of a meter (i.e., two decimal places). All bearings will be rounded to the nearest second of a degree. When rounding computer-generated bearings, the designer must ensure that the rounded numbers for bearings are mathematically consistent.

2. Coordinates. The designer will prepare a table of coordinates for the linear and level data sheet. The table will illustrate the coordinate values for all control points for either the staked centerline or control traverse survey and for the projected centerline. The control points will include the project beginning and ending points; the PC, PI and PT for simple curves; the TS, SC, (Master) PI, CS and ST for spiral curves; and all equations. All coordinates must be computed to at least five decimals and rounded in the table to the nearest four decimals.

For projects using the as-built plans as the basis of horizontal alignment (typically overlay projects), the designer will soft convert the as-built stationing to metric. Retain the degree of accuracy shown on the as-built plans. Also, when existing right-of-way (R/W) plans are used to describe additional R/W acquisition, the designer will ensure that the accuracy of the stationing and bearings matches that of the old R/W plans.

For projects with a new survey (typically reconstruction or major widening projects), new metric stationing should be used.

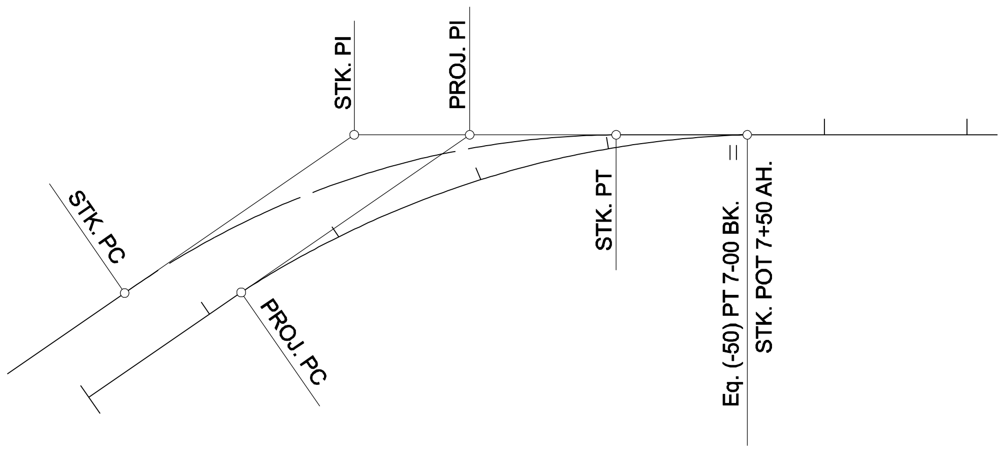
### 9.6.6 Equations

The following will apply to the use of equations in project stationing:

1. Purpose. An equation is used to equate two station numbers — one that is correct when measuring on the line back of the equation and one that is correct when measuring on the line ahead of the equation. Equations should be used where stationing is not continuous throughout a project.

2. Locations. Equations should be computed where design lines become coincident with staked lines. This situation is illustrated in Figure 9.6G.

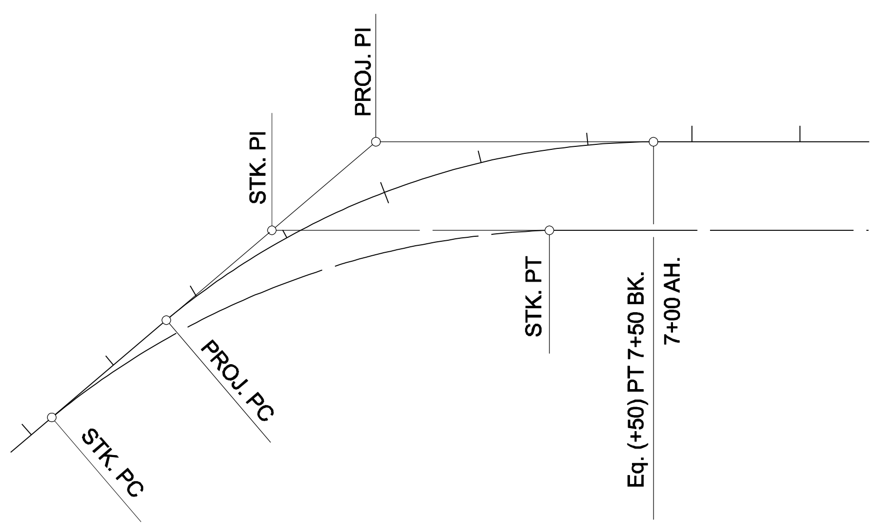
   Equations also should be computed in certain cases where design lines become parallel with staked lines. If the design line remains parallel with the staked line for a considerable distance through numerous cross sections, it is more convenient to compute an equation than to re-station the cross sections. An example of such an equation is illustrated in Figure 9.6H.




*Note: If back station > ahead station, equation is (+). If back station < ahead station, equation is (-).*

**EQUATION WHERE DESIGN LINE BECOMES COINCIDENT**

**Figure 9.6G**




**EQUATION WHERE DESIGN LINE BECOMES PARALLEL WITH STAKED LINE**

**Figure 9.6H**